A Mannual for

Engineering Soil Testing

-photo by Ishwor Khanal

uploads by IOEAGRINEER

pdf by paudelpadamprasad

CONTENTS

EXPERIMENT NO. 1

Moisture Content Determination

Object

To determine the moisture content (water content) of a given soil sample.

Theory and applications

A soil is an aggregate of soil particles having a porous structure. The pores may have water and/or air. The pores are also known as voids. If voids are fully filled with water, the soil is called saturated soil and if voids have only air, the soil is called dry.

Moisture content is defined as the ratio of the mass/weight of water to the mass/weight of solids (Fig. 1.1).

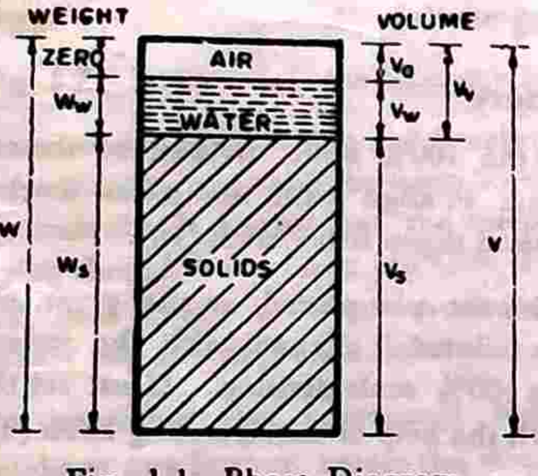


Fig. 1.1 Phase Diagram

$$w = \frac{W_w}{W_s} \qquad (1\text{-}1)$$

Where w = water content

W_w = mass/weight of water

W_s = mass/weight of solids (mass of oven-dry soil)

The mass of water used in the above expression is the mass of free pore water only. Hence for moisture content determination the soil samples are dried to the temperature at which only pore water is evaporated. This tempereture was standardized 105°C to 110°C. Soils having gypsum are dried at 60°C to 80°C.

The quantity of soil sample needed for the determination of moisture content depends on the gradation and the maximum size of particles. Following quantities are recommended[a].

Soil	*Max. quantity used (gm)*
Coarse gravel	1000 to 2000
Fine gravel	300 to 500
Coarse sand	200
Medium sand	50
Fine sand	25
Silt and clays	10 to 25

The methods to determine moisture content in the laboratory are oven-drying, pycnometer, infrared lamp with torsion balance moisture meter. The approximate methods are alcohal burning method and calcium carbide method.

Applications

Moisture content plays an important role in understanding the behaviour of fine grained soils. It is the moisture content which changes the soils from liquid state to plastic and solid states. Its value controls the shear strength and compressibility of soils. Compaction of soils in the field is also controlled by the quantity of water present. Density of soils are directly influenced by its value and are used in calculating the stability of slopes, bearing capacity of soil-foundation system, earth

(a) Lesser the moisture content, greater the quantity of soil to be taken

pressures behind the retaining walls and pressures due to overburden.

The knowledge of determining the moisture content is helpful in many of the laboratory tests such as Atterberg's limits, shear strength compaction and consolidation.

This experiment may be performed by two different methods.

A. Open drying method

B. Torsion balance moisture content

A—OVEN DRYING METHOD

Apparatus

General

1. Containers (non corrodible, air-tight)
2. Balance (accuracy .04 percent of the weight of the soil taken for test).
3. Oven (interior of non-corroding material, thermostatically controlled).
4. Desiccator.
5. Tongs (one pair).

Procedure

1. Clean, dry and weigh the container with lid.
2. Take the required quantity of the soil specimen in the container and weigh with lid.
3. Maintain the temperature of the oven between 105°C and 110°C for normal soils and 60°C to 80°C for soils having loosely bound hydration water or/and organic matter.
4. Dry the sample in the oven till its mass becomes constant. In normal conditions the sample is kept in the oven for not more than 24 hours.
5. After drying remove the container from the oven, replace the lid and cool in the desiccator.
6. Weigh the dry soil in the container with lid.

Precautions

1. The soil specimen should be loosely placed in the container.
2. Over heating should be avoided.
3. Dry soil sample should not be left in open before weighing.

Observations and Calculations

The moisture content is calculated as follows :

$$w = \frac{W_w}{W_s} = \frac{W_2 - W_3}{W_3 - W_1} \times 100 \qquad (1.2)$$

Where W_2 = mass of container with lid+wet soil

W_3 = mass of container with lid+dry soil

W_1 = mass of container with lid

B—TORSION BALANCE MOISTURE METER METHOD

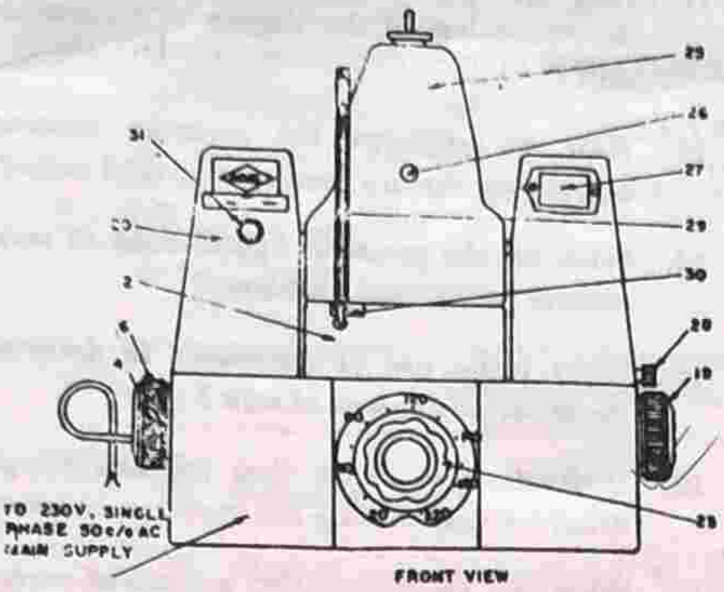
Apparatus

Special

1. Torsion balance moisture meter (0—100% with infrared lamp)
2. Tong

Procedure

1. Set the 100% scale division of the calibrated drum to align with the index mark with the help of drum drive knob (19).
2. With the pan placed on the pivot, check that the pointer is aligned with the index line and the 100% scale division. If not set the pointer with the help of initial setting knob (6).
3. Rotate the drum drive knob anti-clockwise and bring the 0% scale division in line with the index mark, thus prestressing the wire through an amount equal to 100%. (This pre-sets the amount of unbalance. The pointer will now be above the index mark)
4. Raise the lamp housing and carefully distribute the test material evenly on the sample pan until the pointer returns to the index mark. (Approximately 5 grams of the material will be needed in one operation).
5. Lower the lamp housing and switch on the infra-red lamp with the help of the switch provided on the left hand side. Insert the



1. Base
2. Pan house
4. One off switch
6. Initial adjustment knob
19. Drum drive knob
23. Varica knob (for heat control)
24. Cover
25. Lamp housing
26. Lift handle
27. Viewing lens
28. Loaking sore
29. Thermometer
30. Thermometer bracket
31. Indicator lamp

Fig 1.2 Torsion Balance Moisture Meter

thermometer in its socket and bracket. Adjust the variac control knob between 95 and 100 on the scale if it is desired that the temperature of drying should be around 110°C[b] The sample will now begin to loose moisture and the pointer will rise above the index.

6. To determine the percentage reduction of weight at any instant, rotate the drum scale by turning the drum drive knob until the pointer returns to the index Read the percentage directly from the scale. The percent moisture which is read from the scale is the per cent moisture based upon the initial weight of the sample i.e. the wet weight of the sample.

7. The criterion for taking the final reading is that the pointer should remain steady on the index mark which shows that the sample has dried to constant weight. Note the drum scale reading against the pointer which is the percent moisture on the total weight taken. Remove the thermometer from its bracket.

8. For repeating the test use the spare pan so that the pan used first has time to cool and can be cleaned out.

9. Repeat steps 1 to 8 as above with a fresh sample.

Precautions

1. Pan should be cleaned before taking the wet soil in it.
2. For taking the final reading, ensure that pointer should remain constant. It becomes constant normally in 15 to 30 minutes.
3. Temperature should be controlled between 60°C to 80°C for soils having gypsum or/and organic matter. At this temperature pointer becomes constant approximately in 40 to 60 minutes.
4. Instrument should not be subject to any jolting.
5. Do not rotate the initial setting — knob unnecessarily which may lead to snapping.

Observations and Calculations

1. Read the percentage directly from the scale on the drum. This is the moisture content based on the wet mass of the soil.
2. Calculate the moisture content of the soil with respect to dry mass of the soil.

$$w = \frac{m}{(100-m)} \times 100 \qquad (1\text{-}3)$$

Where w = moisture content based on dry mass (%)

m = moisture content based on wet weight, (%)

(b) Keep watch off the column of mercury on the thermometer and when the thermometer records a temperature of 105°C, control the variac in such a manner that there is more rise in the temperature beyond 110°C and the temperature in the housing is maintained at 110°C ± 50°C. If for a particular sample, the temperature is to be higher or lower than 110°C, the variac control knob can be adjusted accordingly.

QUESTIONS

1. Define moisture content (water content).
2. Differentiate between the moisture contents based on wet weight and dry weight of soil. Which one is used in practice ?
3. How do you convert the moisture content based on weight of wet soil to the moisture content based on its dry weight ?
4. Differentiate between moisture content and natural moisture content of a soil.
5. What are free pore water and water of hydration ? Which one do you determine in this test ? Explain.
6. What do you understand by hygroscopic absorbed moisture, contact moisture and surface bound moisture ?
7. What are the factors affecting the hygroscopic moisture ?
8. Why do you dry the soil samples at 105° to 110°C ?
9. What is difference between the air dried and oven dried soil sample ?
10. What is capillary moisture ? How do you differentiate it from natural moisture ?
11. Why does the quantity of soil taken for moisture content determination depend on the size of the soil particles ?
12. How do you use the moisture content in determination of the degree of saturation of soils ?
13. How do you use the moisture content in calculating the dry density and void ratio ?
14. What are the practical applications of moisture content in the field problems ?
15. What is the use of desiccator in determining the moisture content of soils ?
16. How do you check that soil has completely dried for determining the moisture content ?
17. What are the limitations, sources of errors and precautions in pycnometer method to determine the moisture content of soils.
18. What are the limitations of torsion balance moisture meter for determining the moisture content of soils.
19. Compare the sand bath method with alcohal burning method and oven drying method.
20. Compare the calcium carbide rapid moisture meter with infrared torsion balance moisture meter.
21. What is the use of moisture content determination in consolidation test ?

DISCUSSIONS

EXPERIMENT NO. 1

MOISTURE CONTENT DETERMINATION

OBSERVATIONS AND CALCULATIONS

Soil sample No.

TABLE 1

Date

(Oven Drying Method)

Determination No.	1	2	3
(1) Container No.			
(2) Mass of container with lid. W_1 (gm)			
(3) Mass of container with lid + wet soil W_2 (gm)			
(4) Mass of container with lid + dry soil, W_3, (gm)			
(5) Mass of water, $W_w = W_2 - W_3$ (gm)			
(6) Mass of dry soil, $W_s = W_3 - W_1$ (gm)			
(7) Moisture content, $w = W_2 - W_3 / W_3 - W_1 \times 100$, (%)			

Result

Average Moisture Content, w (%)

EXPERIMENT No. 2

Grain Size Analysis - Mechanical Method

Object

To classify the coarse grained soils.

Theory and Applications

Soils having particles larger than 0.075 mm size are termed as coarse grained soils. In these soils more than 50% of the total material by mass is larger than 75 micron. Coarse grained soil may have boulder, cobble, gravel and sand.

Coarse grained soils may have rounded to angular bulky, hard, rock particles with the following sizes :

Boulder-more than 300 mm dia.

Cobble - smaller than 300 mm and larger than 80 mm dia.

Gravel (G) - smaller than 80 mm and larger than 4.75 mm

Coarse gravel - 80 mm to 20 mm

Fine gravel - 20 mm to 4.75 mm

Sand (S) smaller than 4.75 mm and larger than 0.075 mm

Coarse : 4.75 mm to 2 mm

Medium : 2.0 mm to 425 micron

Fine : 425 micron to 75 micron

Name of the soil is given depending upon the maximum percentage of the above components.

Soils having less than 5% particles of size smaller than 0.075 mm are designed by the symbols :

GW — Well graded gravel

GP — Poorly graded gravel

SW — Well graded sand

SP — Poorly graded sand

Soils having greater than 12% of particles of size smaller than 0.075 mm are designated by the following symbols :

GM or GC : Silty gravel or clayey sand

SM or SC : Silty sand or clayey sand

Dual symbols are used for the soils having 75 micron passing between 5 to 12%.

Dry sieve analysis is performed for cohesionless soils if fines are less than 5%.

Wet sieve analysis is done if fines are more than 5% and of cohesive in nature.

Gravels and sands may be either poorly graded (uniformly graded) or well graded depending upon the value of coefficient of curvature and uniformity coefficient.

Coefficient of curvature may be estimated as :

$$C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}} \tag{2-1}$$

D_{60} = diameter at 60% finer

D_{30} = diameter at 30% finer

D_{10} = diameter at 10% finer

It should lie between 1 and 3 for well graded gravels and sands.

Uniformity coefficient

$$C_u = \frac{D_{60}}{D_{10}} \tag{2-2}$$

Its value should be more than 4 for well-graded gravels and more than 6 for well graded sands. (I.S : 1498 - 1970).

Applications

The percentage of different sizes of soil particles coarser than 75μ is determined. Coarse grained soils are classified mainly by sieve analysis. The grain size distribution curve gives an idea regarding the gradation of the soil i.e. it is possible to identify whether a soil is well graded or poorly graded. In mechanical soil stabilization, the main principle is to mix a few selected soils in such a proportion

that a desired grain size distribution is obtained for the design mix. Hence for proportioning the selected soils, the grain size distribution of each soil is to be first known.

Apparatus

Special :

1. Ist set sieves of sizes 300 mm, 80 mm, 40 mm, 20 mm, 10 mm and 4.75 mm.
2. 2nd set of sieves of sizes 2 mm, 850 μ, 425 μ, 150 μ and 75 micron.
3. Sodium hexametaphosphate (for cohesive soils)
4. Mechanical shaker (optional)
5. Brush
6. Rubber Pestle and Motor

General :

1. Balances (One of accuracy = 1.0 gm, other of accuracy = 0.1 gm.)
2. Weights and weight box
3. Oven
4. Desiccator
5. Drying crucibles
6. Tray/bucket
7. Water

Procedure

1. Take suitable quantity of oven-dry soil depending upon the maximum size of material present in.

TABLE 2.1

Substantial quantities in the soil

Maximum size of material present in substantial quantities	*Quantity to be taken kg*
80 mm	60.0
20 mm	6.5
4.75 mm to 75 micron	0.5

2. (a) If soil seems to have more than 5% of cohesive soils, the soil taken in step (1) is spread out in the large tray or bucket and covered with water. Two grams of sodiumhexa metaphosphate per litre of water used is then be added to the soil. The mix is thoroughly stirred and left for soaking.

(b) The soaked soil specimen is washed on 75 micron I. S. sieve until the water passing the sieve is clean.

(c) The fraction retained on sieve is tipped without loss of material in a tray, dried in the oven at 105° to 110°C and weighed.

(d) Loss in mass will give percentage passing 75 micron sieve.

Sieving for coarser than 4.75 mm size

3. Clean the Ist set of sieves and pan with brush

4. Sieve the soil first through I.S. sieves of first set i.e. 80 mm, 40 mm, 20 mm, 10 mm and 4.75 mm manually or using a mechanical shaker for 5-10 minutes.

5. Weigh the material retained on each sieve to 1.0 gm.

Sieving for soil passing from 4.75 mm size

6. Clean the sieve and pan with brush and weigh to 0.1 gm.

7. Sieve the soil through 2nd set of sieves i.e., 2 mm, 850 μ, 425 μ, 150 μ and 75 micron using a mechanical shaker for 10 minutes.

8. Weigh to 0.1 gm each sieve and pan with soil retained on them. The sum of the retained soil mass is checked against the origial mass of soil taken.

Precautions

1. While drying, the temperature of the oven should not be more than 105°C because higher temperature may cause some permanent change in the -75 micron materials.

2. During shaking, soil sample should not be allowed to come out.

3. In wet analysis, all cohesive soil adhering to large size particles should be removed by water.

4. For plotting, per cent finer should be etermined with respect to the total soil taken for iitial analysis.

bservations and Calculations

1. All observations are entered in prescribed bservation tables. Most of the calculations are one in the observation tables itself. In table 1 ie cumulative mass of soil fraction retained on ach sieve is calculated. The cumulative ercentage of soil fraction retained on each sieve calculated on the basis of the total weight of the ample taken for this analysis. Percentage finer calculated by subtracting the percentage retained rom 100.

2. In observation table 2 the cumulative mass f soil fraction retained on each sieve is calculated. he cumulative percentage of soil fraction retained n each sieve is calculated on the basis of the mass f the sample passing 4.75 mm I.S. sieve. The ombined gradation on the basis of the total soil ample taken for analysis is then calculated.

3. Diameter (mm) is taken on log scale and ercent finer on ordinary scale for plotting the rain size distribution curve. Use recommended raph paper.

4. Read the diameters corresponding to 60%, 0% and 10% finer. Calculate coefficient of urvature and uniformity coefficient.

5. Read also the percentage of each soil from he graph paper.

Determination No.	1	2	3
D_{60}			
D_{30}			
D_{10}			
C_c			
C_u			

QUESTIONS

1. What is the purpose of sieve analysis ?
2. Why do you classify the soils ?
3. What are the coarse grained and fine grained soils as per Indian Standard classification of soils for general engineering purposes ?
4. How do you classify the soils by sieve analysis ? Can you classify all types of soils by sieve analysis ?
5. What is coefficient of curvature (C_c) ? Where is it used ?
6. What is coefficient of uniformity (C_u) ? How do you determine it ? What are its applications ?
7. What do you understand by well graded, and uniformly graded soils ?
8. What do you understand by dry and wet sieve analysis ? Which one did you perform ? Why ?
9. What is the grain size distribution curve ? Why do you use a semi-log graph paper for plotting it ?
10. Draw the grain size distribution curves for poorly graded, well graded and uniformly graded soils.
11. What do you understand by GW, GP, GM, GC, SW, SP, SM, SC, SW–SM, GP–SC ? What are the maximum and minimum percentages of fines in these soils ?
12. Classify the soil with the following test data

(i)	Gravel	15%
(ii)	Sand	75%
(iii)	Fines	10%
(iv)	C_u	9
(v)	C_c	1.2

13. What are the applications of the results of sieve analysis in field problems ?
14. What are the number of the sieves which you are using ? What do you understand by these number ?

15. What is the difference between Indian Standard and U.S. Standard numbers ?

16. How much soil did you take for sieve analysis ? What are the considerations to fix the quantity of soil to be taken for sieve analysis ?

17 What is the accuracy of the balance used in this test ? What is the basis of selecting this accuracy of the balances in sieve analysis ?

18. How do you calculate percentage finer and percentage fines ? Where are these used ?

19. What type of soil sample do you need for sieve analysis ? Why ?

20. What are the main sources of errors and precautions in sieve analysis ?

DISCUSSIONS

EXPERIMENT No. 2

GRAIN SIZE ANALYSIS - MECHANICAL METHOD
OBSERVATIONS AND CALCULATIONS

Soil Sample No.

TABLE 1

Date

(Soil coarser than 4.75 mm)

Mass of total soil sample taken for analysis, kg =

Sieve No.	*Sieve opening (mm)*	*mass of sieve (gm)*	*mass of Sieve + Soil (gm)*	*mass of soil retained (4)—(3) (gm)*	*Cumulative mass of soil retained (gm)*	*Cumulative % of soil retained (%)*	*% finer (passing) 100—(7)*	*Remarks*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
80 mm								
40 mm								
20 mm								
10 mm								
4.75 mm								
Pan								

Soil Sample No.

TABLE 2

Date

(Soil passing from 4.75 mm Sieve and retained on 75 Micron Sieve)

(i) Mass of total soil sample taken for analysis, kg =

(ii) % of soil sample passing from 4.75 mm sieve =

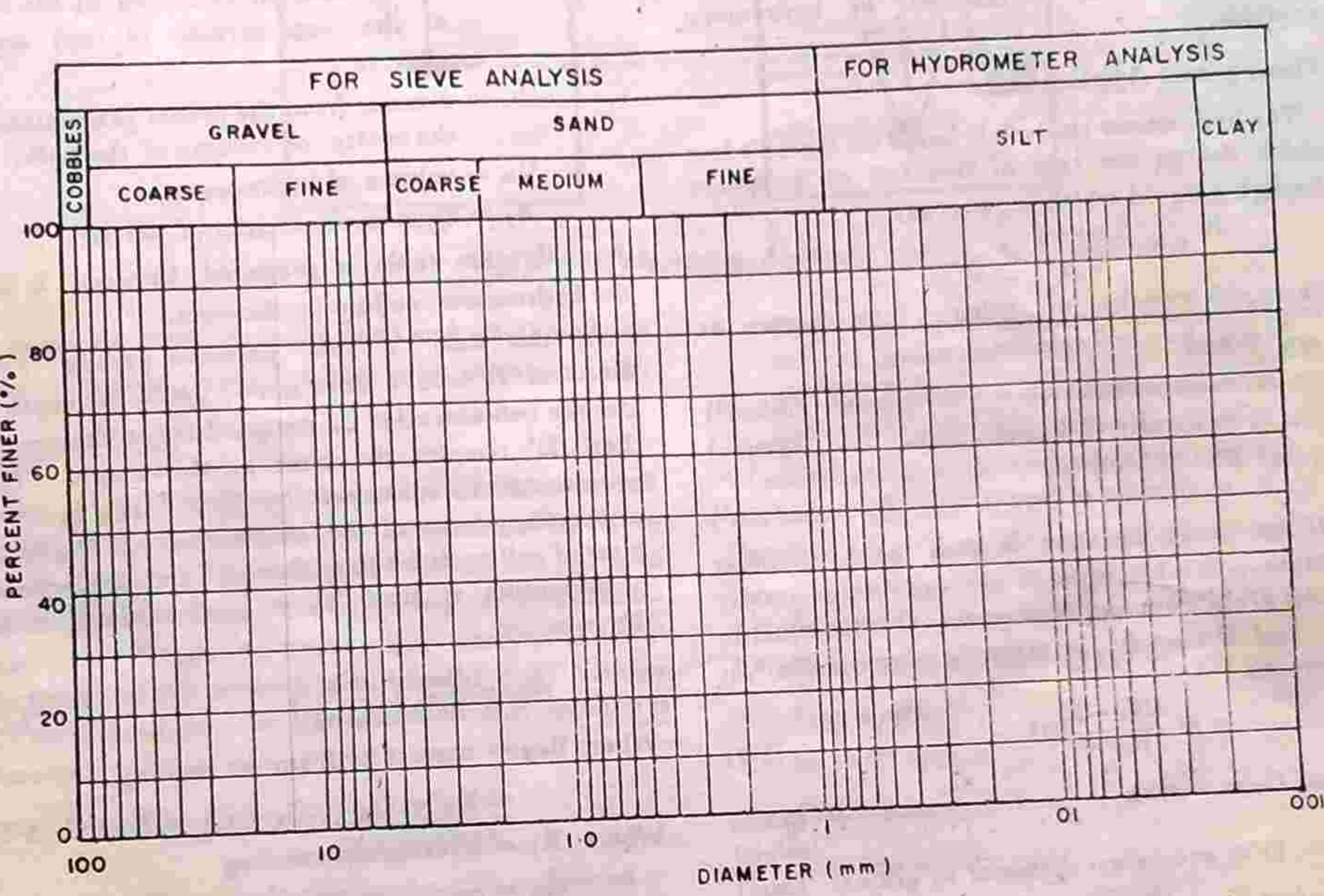
(iii) Mass of soil sample taken for this analysis kg =

Sieve No.	*Sieve opening (mm)*	*Mass of Sieve (gm)*	*Mass of Sieve + Soil (gm)*	*Mass of soil retained (4)—(3)*	*Cumulative Mass of Soil retained*	*Cumulative % of soil retained*	*% finer w.r.t. 4.75 mm passing*	*Combined % finer w.r.t. totla soil sample (8)×(ii)*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
2 mm								
850 micron								
425 micron								
150 micron								
75 micron								
Pan								

EXPERIMENT No. 2 & 3

GRAIN SIZE ANALYSIS

Soil Sample No. Graph Sheet (Semilog) Date



Results

Boulder + Cobble, % =

Gravel, % =

Sand, % =

Silt or clay, % =

Classification =

Grain Size Analysis - Hydrometer Method

Object

To determine the percentages of various soil grains (finer than 75 micron) by hydrometer analysis.

Theory and Applications

The hydrometer analysis is based on Stocke's law which defines the rate of free fall of a sphere through a liquid which is given as :

$$v = \frac{2}{9}\frac{r_s - r_1}{\eta} r^2 \qquad (3\text{-}1)$$

Where v = velocity of sphere (also known as terminal velocity, (cm/sec)

r_s = density (unit mass of sphere, (gm/cm^3)

r_1 = density of liquid, (gm/cc)

r = radius of sphere, (cm)

η = viscosity of liquid, (gram/sec cm^2)

If the avove equation is used for hydrometer analysis, r_s is taken equal to average specific gravity of soil grain assuming unit mass of water equal to one and if viscosity is taken in dyne sec/cm^2, it becomes :

$$v = \frac{(G_s - 1)}{1800\eta} D^2 \qquad (3\text{-}2)$$

Where G_s = average specific gravity of grains (solids)

D = equivalent diameter of grains, (mm)

$$\text{Hence } D = \sqrt{\frac{1800\,\eta}{G_s - 1}\, v} \qquad (3\text{-}3)$$

If particles of diameter D travel through a distance h (cm) in time t minutes)

$$D = \sqrt{\frac{30\,\eta\, h}{(G_s - 1)t}} \qquad (3\text{-}4)$$

In figure, 3.1, h is determined by the equation

$$h = h_1 + \left(h_o - \frac{V_H}{2A_J}\right) \qquad (3\text{-}5)$$

Where h_1 = distance from the lowest graduation to the graduation mark (R) of the stem at the top surface of soil water mixture,

h_o = distance from the lowest graduation to the centre of volume of the bulb.

V_H = volume of hydrometer

A_J = cross-sectional area of the jar

A calibration table is prepared between h and the hydrometer reading on the stem.

At this time 't' all particles greater than diameter 'D' would have settled below the depth h. But the concentration of the particles of size smaller than 'D' remains the same at this depth. This concentration is measured by hydrometer in terms of specific gravity of the suspension. If W_d is the mass of soil particles finer than 'D' per unit volume of suspension at time 't', it can be calculated by the equation :

$$W_d = \frac{R_{c2}}{1000}\left(\frac{G_s}{G_s - 1}\right) \qquad (3\text{-}6)$$

Where R_{c2} = correct hydrometer reading

$= R_h + C_m \pm C_t - C_d = R_h \pm C \quad (3\text{-}7)$

Where R_h = hydrometer reading

C_m = correction due to meniscus

C_t = correction due to temperature

C_d = correction due to dispersing agent

C = composite correction.

If W_D is the total mass of soil taken in the original 1000 cc of suspension, the percentage finer than 'D' is obtained from equation :

$$\text{Percentage finer, } N = \frac{R_{c2}}{W_D}\left(\frac{G_s}{G_s - 1}\right) \times 100 \qquad (3\text{-}8)$$

Hence at any time t, the size of particles is

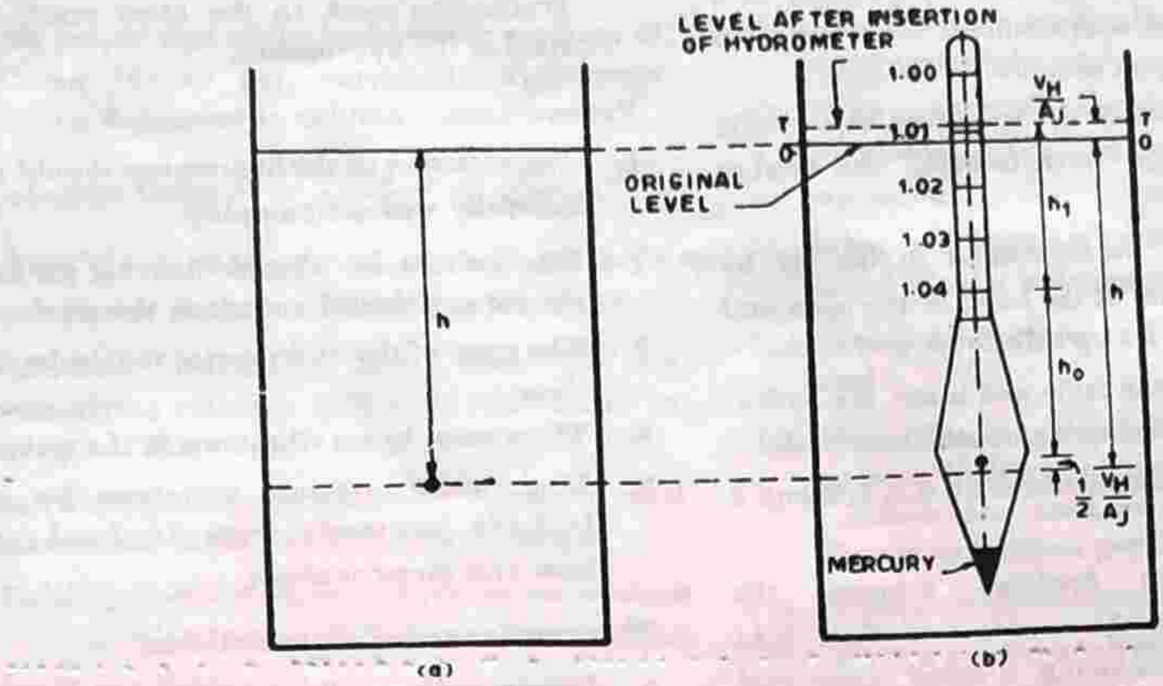


Fig. 3.4 Hydrometer Analysis

calculated from equation (3-4) and (3-5) and the corresponding percentage finer from equation (3-3).

Applications

In a given soil the percentage of different soil particles upto 75 micron is determined by sieve analysis, but the percentage of various soil particles finer than 75 micron is determined by hydrometer analysis. Hence the hydrometer analysis is useful in knowing the percentage of silt and clay. Activity of clays may also be estimated if clay fraction is known.

$$\text{Activity} = \frac{\text{plasticity index}}{\text{clay fraction}}$$

Activity helps in classifying the soils as follows :

Activity	*Classification*
< 0.75	Inactive
0.75--1.25	Normal
> 1.25	Active

Apparatus

Special :

1. Hydrometer (calibrated at 27°C, range 0.995 to 1.030 g/cc).
2. Cylinders or Jars (two, volume 1000 cc, graduated, diameter about 7 cm, height 30 cm)
3. Dispersing agent solution (containing 33 gm of sodium hexameta - phosphates and 7 gm of sodium carbonate in distilled water to make one litre of solution).
4. Mechanical stirrer (high speed ⊳ 5000 rpm).

General

1. Balance (accuracy 0.01 gm)
2. Thermometer (accuracy 0.5°C)
3. Stop watch
4. Sieve 75 micron
5. Centimeter scale
6. Distilled water
7. Soil weighing dish

Procedure

1. Take 50 gm of pretreated dry soil passing from 75 micron sieve.
2. Place the soil in an evaporating dish and cover it up with 100 cc of dispersing solution and warm gently for about 10 minutes.
3. Transfer the sample to the cup of mechanical stirrer using distilled water until the cup is three fourth full and operate the mixer for about four minutes.

4. Meanwhile keep the clean hydrometer in a 1000 cc jar filled with distilled water and 100 cc dispersing agent solution.
5. After stirring, wash the specimen into a 1000 cc jar and enough water to bring the level to 1000 cc mark.
6. Mix thoroughly the suspension in the jar by placing the palm of the hand in the open end and turning the jar up side down and back.
7. Place the jar on the table and insert the hydrometer. Start the stop watch simultaneously.
8. Read the top of the meniscus at 0.5, 1, 2 and 4 minutes.
9. After 4 minutes reading, remove the hydrometer, clean the outside and float it in the second jar containing distilled water and dispersing solution.
0. Record the temperature of the suspension.
11. Take further readings at 8, 15, 30 minutes and 1, 2, 4, 8 and 24 hours after the start of the test. For each of these readings, insert the hydrometer just before the reading.
12. For determining the corrections, read the top and bottom of the meniscus formed on the stem of the hydrometer when it is floating in the second jar containing the distilled water and dispersing agent only.

For calibration of hydrometer

13. Measure the cross-sectional area of the jar for which measure the distance between two graduations on the jar by the scale and record the volume between the two.
14. For determining the volume of the hydrometer, take 1000 cc graduated jar and fill about 700 cc of distilled water in it, record the exact reading. Insert the hydrometer and read the graduation jar. Difference of readings before and after insertion gives the volume of hydrometer.
15. Measure the centre of the volume of the hydrometer from the lowest graduation mark on the stem.
16. Measure the distances from the lowest graduation mark to the other marks on the stem of the hydrometer.

Precautions

1. The insertion of the hydrometer should be done carefully without bumping.
2. The hydrometer should float at the centre of the jar and should not touch the sides.
3. The stem of the hydrometer should be dry and clean.
4. There must be no vibrations in the vicinity.
5. Minimise temperature variations by keeping both the jars away from any local course of heat and direct sunlight.

Observations and Calculations

A. Determination of Particle Size 'D'

(a) Enter all hydrometer readings, after subtracting one and then multiplying the remaining digits by 1000, .hus 1.015 is entered as 15 in column (4) of observation table 1.

(b) Add the meniscus correction in these readings and enter the corrected hydrometer reading R_{c1} in column (7).

(c) From table 2, read the effective depth corresponding to R_{c1} and enter in column (8).

(d) Calculate $\sqrt{h/t}$ with the values of column (3) and (8). Enter in column (9).

(e) Read the viscosity values corresponding to temperature of column (5) Appendix and enter in column (10).

(f) Calculate the factor $M = \sqrt{\frac{30\,\eta}{(G_s-1)}}$ and enter in column (11).

(g) Calculate the particle size 'D' by multiplying the value of column (9) with (11) and enter in column (12).

B. Determination of 'Percentage Finer'

(h) Find the composite correction by taking the difference between the top meniscus reading taken in step (12) and 1,000. It may be positive or negative. Enter in column (6).

(i) Add the composite correction of column (6)

with proper sign to the hydrometer readings of column (4) to get corrected hydrometer reading R_{c2}, enter in column (13).

(j) Calculate factor $N = \frac{G_s}{(G_s - 1)} \times \frac{100}{W_D}$

where W_D is the mass of dry soil taken for hydrometer analysis. Enter in column (14).

(k) Calculate percentage finer than 'D' by multiplying columns (13) and (14). Enter in column (15).

(l) Calculate percentage finer with respect to total mass of soil taken for mechanical analysis,

Total % finer = % finer by hydrometer analysis × % of 75 μ passing from sieve analysis

Enter in column (16)

(m) Plot on the graph sheet of sieve analysis.

QUESTIONS

1. What is hydrometer analysis ?
2. What is sedimentation analysis ?
3. Differentiate between mechanical, hydrometer and sedimentation analysis ?
4. What is Stoke's Law ? What are its assumptions ?
5. How does Stoke's law help in hodrometer
6. How do you satisfy the assumptions of Stoke's law in hydrometer analysis ?
7. What is the effect of the size of soil particles on their velocity in soil water suspension ?
8. What is the terminal velocity of soil grains ?
9. What is the effect of density of soil grains, density of water, viscosity of water and temperature on terminal velocity of soil grains in soil-water solution ?
10. Write an expression to calculate the diameter of soil grains. What is effective height in this expression ?
11. What is hydrometer correction ? Where is it used ? How is it determined ?
12. What is hydrometer calibration ? Where is it used ?
13. What is the role of dispersing/deflocculating agent in hydrometer analysis ? Name the most common one used in hydrometer analysis? How is its solution pepared ?
14. What does hydrometer measure ?
15. What is pipette analysis ? Differentiate it from hydrometer analysis ?
16. What are the applications of hydrometer analysis ?
17. What is the range of your hydrometer ? What does it mean ?
18. What is meniscus correction ? How do you determine it ? Where is it used ?
19. What is temperature correction ? How do you determine it ? Where is it used ?
20. What is dispersing agent correction ? How do you determine it ?
21. What is composite correction ? How is it obtained ? Where is it applied ?
22. What is the normal range of soil particles which may be classified by hydrometer analysis ? Why ?
23. What are the sources of error and precautions to be taken in a hydrometer analysis.

DISCUSSIONS

EXPERIMENT No. 3

GRAIN SIZE ANALYSIS-HYDROMETER METHOD

OBSERVATIONS AND CALCULATIONS

Date

Soil sample No.

TABLE 1

(i) Percentage of 75 μ passing (from sieve analysis) =

(ii) Mass of dry soil taken (75 micron passing) W_D, (gm) =

(iii) Specific gravity of soil grains, G_s =

(iv) Top meniscus reading on hydrometer stem (taken in step 12) =

(v) Bottom meniscus reading on hydrometer stem (taken in step 12) =

(vi) Meniscus correction, $C_m = +[(v) - (iv)]$ =

Date	Time	Elapsed time (t) (min)	Hydro meter Reading R_h	Temperature T(°C)	Composite Correction ±C	$R_{c1} = R_h + C_m$	Effective depth h(cm)	$\sqrt{h/t}$	Viscosite, η (gm/sec/cm²)	Factor M	Particle 'C' (mm) (9)×(11)	$R_{c2} = R_h \pm C$ (4)+(6)	factor N	% finer w. r. to wt. W_D F (13)×(14)	% finer w. r. to total mass (15)×(i)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)

EXPERIMENT No. 3

GRAIN SIZE ANALYSIS - HYDROMETER METHOD

OBSERVATIONS AND CALCULATIONS

TABLE 2 Date

(Hydrometer - Calibration)

(i) Hydrometer No. =

(ii) Sedimentation Jar No. =

(iii) Volume of hydrometer, V_H, cm^3 (determined in step 14) =

(iv) Volume between any two graduations on jar, cm^3 =

(v) Length between above two graduations on jar, cm =

(vi) Cross-sectional area of jar, A_J = (iv) / (v), cm^2 =

(vii) Distance between lowest graduation and neck, cm

(viii) Distance between neck and centre of volume of bulb, cm =

(ix) Distance between lowest graduation and centre of the bulb, h_o (vii) + (viii), cm =

(x) Constant, $K = \left(h_o - \frac{V_H}{2A_J} \right)$ =

Hydrometer Reading R_h (R_{el})	Distance from lowest graduation to R_h h_1 (cm)	Effective depth h (cm)
(1)	(2)	(3)

EXPERIMENT No. 4

Liquid and Plastic Limit Tests

Object

(a) To determine liquid limit
(b) To determine plastic limit
(c) To classify the soil
(d) To find flow index
(e) To find toughness index

Theory and Applications

Liquid limit is the water content at which soil passes from zero strength to an infinitesimal strength, hence the true value of liquid limit can not be determined. For determination purpose liquid limit is that water content at which a part of soil, cut by a groove of standard dimensions, will flow together for a distance of 1.25 cm under an impact of 25 blows in a standard liquid limit apparatus. The soil at the water content has some strength which is about 0.17 N/cm² (17.6 g/cm²). At this water content soil just passes from liquid state to plastic state.

The moisture content at which soil has the smallest plasticity is called the plastic limit. Just after plastic limit the soil displays the properties of a semi-solid. Change in state at these limits are shown in Fig. 4.1.

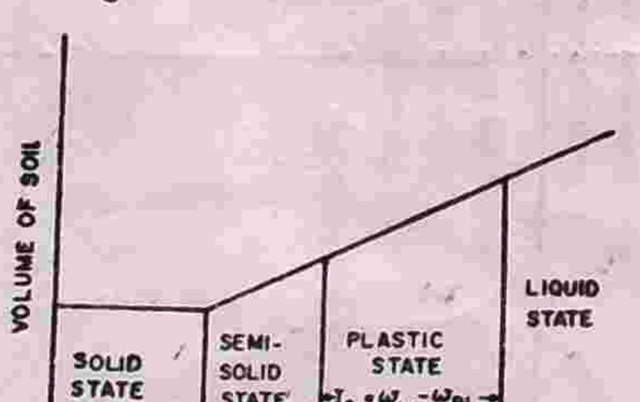


Fig. 4.1 Relationship between Volume of Soil and its Moisture Content.

For determination purpose, the plastic limit is defined as the water content at which a soil will just begin to crumble when rolled into a thread of 3 mm in diameter.

The difference in moisture contents or interval between the liquid and plastic limits is termed the plasticity index. Knowing the liquid limit and plasticity index, soil may be classified with the help of plasticity chart according to Indian Standard on soil classification (IS 1498-1970), Fig. 4.2.

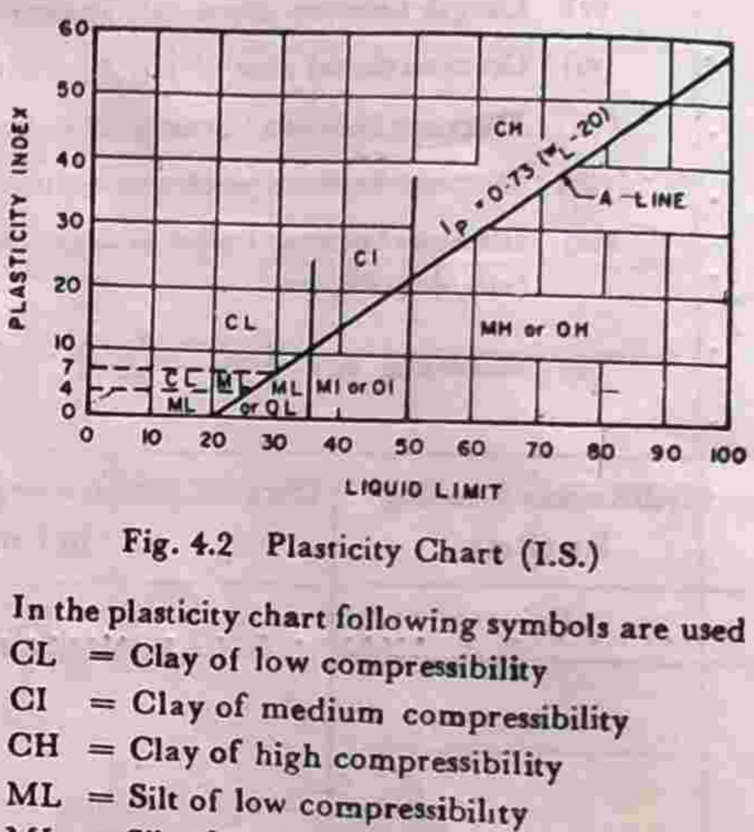


Fig. 4.2 Plasticity Chart (I.S.)

In the plasticity chart following symbols are used :

CL = Clay of low compressibility
CI = Clay of medium compressibility
CH = Clay of high compressibility
ML = Silt of low compressibility
MI = Silt of medium compressibility
MH = Silt of high compressibility
OL = Organic soil of low compressibility
OI = Organic soil of medium compressibility
OH = Organic soil of high compressibility

Applications

The values of liquid limit and plastic limit are directly used for classifying the fine grained cohesive

soils according to Indian Standard on soil classification. Once the soil is classified, it helps a lot in understanding the behaviour of soils and selecting the suitable methods of design, construction and maintenance of the structures made up or/and resting on soils.

The values of these limits are also used in calculating the flow index, toughness index, and relative plasticity index which are useful in giving an idea about the plasticity, cohesiveness, compressibility, shear strength, permeability, consistency and state of cohesive soils. Atterberg (1911) shows the correlations between the plasticity index, soil type, degree of plasticity and degree of cohesiveness.

Plasticity index	Soil type	Degree of plasticity	Degree of cohesiveness
0	Sand	Non-plastic	Non cohesive
<7	Silt	Low-plastic	Partly cohesive
7–17	Silt clay	Med. plastic	Cohesive
> 17	Clay	High plastic	Cohesive

Apparatus

Special

1. Casagrande liquid limit device
2. A.S.T.M. and B.S. grooving tool (Casagrande type)
3. Glass plate 20 × 15 cm
4. 425 micron I.S. sieve
5. 3 mm diameter rod.

General

1. Spatula 2. Basin (300 c.c. capacity) 3. Balance (0.01 gm sensitivity) 4. Water content tins or crucibles 5. Drying oven 6. Distilled water 7. Measuring cylinder 8. Desiccator

Procedure

(a) Liquid Limit :

1. Adjust the cup of the liquid limit apparatus with the help of grooving tool gauge and the adjustment plate to give a drop of exactly 1 cm on the point of contact on base.

2. Take about 120 gm of an air-dried sample passing 425 micron sieve.

3. Mix it thoroughly with some distilled water to form a uniform paste.

4. Place a portion of the paste in the cup of the liquid limit device, smooth the surface with spatula to a maximum depth of 1 cm. Draw the grooving tool through the sample along the symmetrical axis of the cup, holding the tool perpendicular to the cup.

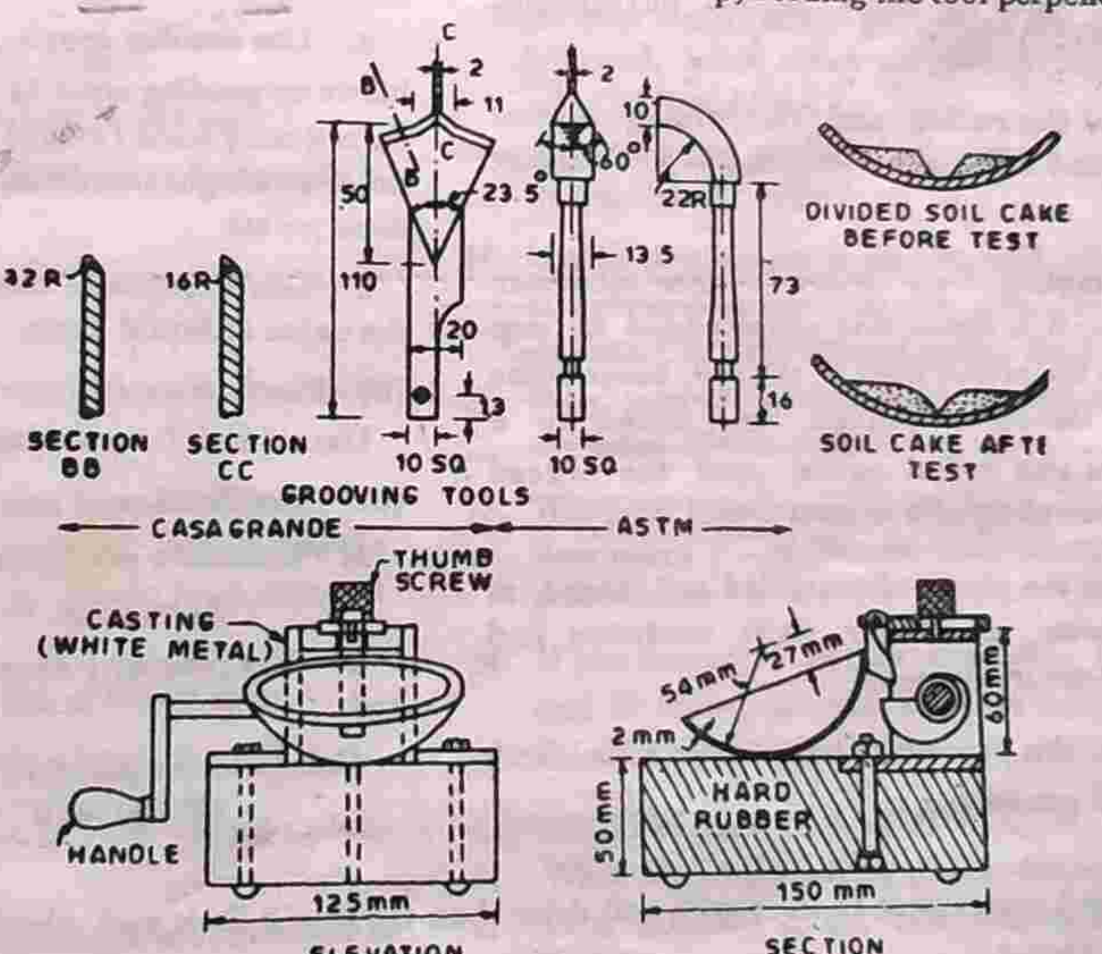


Fig. 4.3 Apparatus with Dimensions for Liquid Limit Test

7

5. Turn the handle at a rate of 2 revolutions per second and count blows until the two parts of the soil sample come into contact at the bottom of the groove along a distance of 10 mm.

6. Transfer about 15 gm of the soil forming the edges of the groove that flowed together to a water content tin, and determine the water content by oven drying.

7. Transfer the remaining soil in the cup to the main soil sample in the basin and mix thoroughly after adding a small amount of water[a].

8. Repeat steps 4, 5 and 6. Obtain at least four sets of readings in the range of 10 to 40 blows.

(b) Plastic Limit :

1. Take about 30 gm of air dried sample passing 425 micron sieve.

2. Mix thoroughly with distilled water on the glass plate until it is plastic enough to be shaped into a small ball.

3. Take about 10 gm of the plastic soil mass and roll it between the hand and the glass plate to form the soil mass into a thread. If diameter of thread becomes less than 3 mm without cracks, it shows that water added in the soil is more than its plastic limit, hence the soil is kneaded further and rolled into thread again.

4. Repeat this rolling and remoulding process until the thread starts just crumpling at a diameter of 3 mm.

5. If crumpling starts before 3 mm diameter thread in step 3, it shows that water added in step 2 is less than the plastic limit of the soil, hence some more water should be added and mixed to a uniform mass and rolled again, until the thread starts just crumpling at a diameter of 3 mm.

6. Collect the pieces of crumbled soil thread at 3 mm diameter in an air tight container and determine moisture content.

7. Repeat this procedure twice more with fresh samples of 10 gm each.

Precautions

1. Use distilled water in order to minimise the possibility of iron exchange between the soil and any impurities in the water.

2. Soil used for liquid and plastic limit determinations should not be oven dried prior to testing.

3. In liquid limit test, the groove should be closed by a flow of the soil and not by slippage between the soil and the cup.

4. After mixing distilled water to the soil sample, sufficient time should be given to permeate the water throughout the soil mass.

5. Wet soil taken in the container for moisture content determination should not be left open in the air even for some time, the containers with soil samples should either be placed in desiccator or immediately be weighed.

6. For each test, cup and grooving tool, should be clean.

Observations and Calculations

(a) Liquid Limit (L.L. or $w_{L.L.}$)

1. Use table 1 for recording the number of blows and calculating the moisture contents.

2. Use semilog graph paper, take number of blows on semilog scale (x-axis and water contents on ordinary scale (y-axis). Plot all the points and draw a straight line (flow curve) passing through these points.

3. Read the water content at 25 blows which is the value of liquid limit.

(b) Plastic limit (P.L. or $w_{P.L.}$)

Use table 2 for calculating the plastic limit.

(c) Classification of soil.

1. Calculate plasticity index (P.I. or I_b)

$$I_b = w_{L.L.} - w_{P.L.} \tag{4-1}$$

2. Use plasticity chart for classification of given soil.

or

Calculate the plasticity index of 'A' line

$$(P.I.)_A = 0.73\,(w_{L.L.} - 20) \tag{4-2}$$

(a) It is found convenient to start with soil drier than the liquid limit and obtain values by increasing the water content.

where $w_{L.L.}$ is in percentage

If P.I. > (P.I.)$_A$ the soil is clay

If P.I. < (P.I.)$_A$ the soil is silt

L.L. = 0—35 low compressibility

35—50 medium compressibility

⊳ 50 high compressibility

(d) Flow Index (F.I. or I_F)

1. Extend the flow curve at both ends so as to intersect the ordinates corresponding to 10 and 100 blows.

2. Read the water contents at 10 and 100 blows. Difference of these two water contents is equal to flow index.

or

The flow index may be calculated from the eq.

$$I_F = \frac{w_1 - w_2}{\log_{10} \frac{N_2}{N_1}} \qquad (4\text{-}3)$$

w_1 = water content in % at N_1 blows

w_2 = water content in % at N_2 blows

(e) Toughness Index (T.I. or I_T)

$$\text{Tougness Index } I_T = \frac{\text{Plasticity Index}}{\text{Flow Index}} = \frac{I_P}{I_F}$$

QUESTIONS ON LIQUID LIMIT

1. What do you understand by liquid limit ?
2. How do you define liquid limit to determine it in the laboratory ?
3. It is possible to determine the true value of liquid limit ?
4. What is the shear strength of soil at liquid limit, determined by you ?
5. Two clays obtained from two different pites have different values of liquid limit. Are the shear strength values at liquid limit different or the same ?
6. What is consistency of soil at liquid limit ?
7. What is the state of soil at liquid limit ?
8. What changes in soil properties do take place at liquid limit ?
9. Is liquid limit of a soil a natural or conventional soil index ?
10. What is the relationship between liquid limit and natural water content of the soil ?
11. Why the liquid limits of 2 samples obtained from two sites are different ?
12. Why may the liquid limits of 2 samples obtained from the same site be different ?
13. If there are two soils A and B, whose liquid limits are 60% and 40% and natural moisture content of both the soils is 30%. In which soil do you expect more shear strength and settlement at their liquid limits and natural moisture contents ?
14. In question 13 which soil does have more permeability ?
15. In question 13 if plastic limit of both the soils is 20 what are the corresponding consistency at their natural moisture contents ?
16. What are the practical uses of liquid limit ?
17. Who developed this liquid limit apparatus ?
18. Is there any other apparatus to determine liquid limit ? If yes, who developed that apparatus ? What are its relative merits and demerits over that ?
19. If the height of cup, speed of cup, type of water given in the standard procedure are not truely followed, what effect do you expect on the value of liquid limit ?
20. Are you using undisturbed sample or remoulded sample ? Why ?
21. If oven dry sample is used instead of air dried sample as mentioned in the procedure, what is the effect on the value of liquid limit ?
22. Why semi-log graph paper is used to estimate the value of liquid limit ?
23. What do you understand by flow curve and flow index ? What do you interprete from these values ?
24. If you have only one set of reading between 20 and 30 blows, can you estimate fairly accurate value of liquid limit ?

QUESTIONS ON PLASTIC LIMIT

1. What is understood by plastic limit ?
2. Is it possible to get the true value of plastic limit ?

3. How the plastic limit is defined to determine it in the laboratory ?

4. What is plastic state ? What is the state of soil at plastic limit ? Do different soils at their plastic limits have the same state ?

5. What is the consistency of soil at plastic limit ? Do different soil at their plastic limits have different consistencies ?

6. Is plastic limit a natural or conventional soil index ?

7. Why are the plastic limits of the samples obtained from two sites different ?

8. Why may the plastic limits of two sample obtained from the same site be different ?

9. Can plastic limit of a soil be more than its liquid limit or/and natural moisture content ? Explain.

10. What is the degree of saturation at plastic limit ?

11. What happens when water content of a soil is reduced from liquid limit to plastic limit ?

12. Do different soils have the same shear strength at their plastic limits. Justify.

13 What is plasticity index ? Compare two soils of different plasticity index but having same liquid limit with respect to dry strength, toughness, permeability, rate of volume change, cohesivness and degree of plasticity.

14. What are relative plasticity index, liquidity index, consistency index and water plasticity ratio ?

15. There are two soils with the following values :

Soil	*Liquid Lt.* (%)	*Plastic Lt.* (%)	*Natural moisture content* (%)
A	70	30	40
B	55	25	40

i) Find out the plasticity index, relative plasticity index.

(ii) Classify both the soils from plasticity chart.

(iii) Compare their shear strength at their liquid limit, plastic limit and natural moisture content.

(iv) Compare the compressibility of the two soils at their liquid limit, plastic limit and natural moisture contents.

(v) Compare change in volume from liquid limits to natural moisture content and plastic limit in the two cases.

(vi) Compare with respect to cohesiveness, permeability, dry strength, toughness and degree of plasticity.

(vii) Note states and consistencies of both the soils at natural moisture contents.

16. What are the practical applications of plastic limit, plasticity index and relative plasticity index of soil ?

17. What type of samples are used to determine the plastic limit i.e. undisturbed or remoulded ? Why ?

18. How does oven dry soil sample affect the value of plastic limit ?

19. Why do you use soil passing from 425 μ sieve to determine the plastic limit while its value is used to classify only the fine grained soils, which is a passing from 75 μ sieve ?

20. What is the effect of soils between 425 μ and 75 μ on the plastic limit ?

21. Why the distilled water is used to determine the plastic limit ? If natural water is having some impurities, would you like to use distilled water or natural water ?

22. What is size of thread you are making to determine the plastic limit ? Why ?

23. If a thread of 5 mm is made instead of 3 mm what is the effect on plastic limit ?

DISCUSSIONS

EXPERIMENT No. 4

LIQUID AND PLASTIC LIMITS

OBSERVATIONS AND CALCULATIONS

TABLE 1

Soil Sample No. Liquid Limit Date

Determination No.	1	2	3	4	5
(1) No. of blows					
(2) Container No.					
(3) Mass of container + wet soil, (gm.)					
(4) Mass of container + dry soil, (gm.)					
(5) Mass of water (3)−(4), (gm.)					
(6) Mass of container, (gm.)					
(7) Mass of dry soil (4)−(6), (gm.)					
(8) Moisture content (5)/(7) × 100, (%)					

TABLE 2

Soil Sample No. Plastic Limit Date

Determination No.	1	2	3
(1) Container No.			
(2) Mass of container + wet soil, (gm.)			
(3) Mass of container + dry soil, (gm.)			
(4) Mass of water, (2) − (3), (gm.)			
(5) Mass of container, (gm.)			
(6) Mass of dry soil, (3) − (5), (gm.)			
(7) Plastic limit, (4/6) × 100, %			

Average Plastic limit =

EXPERIMENT No. 4

LIQUID LIMIT

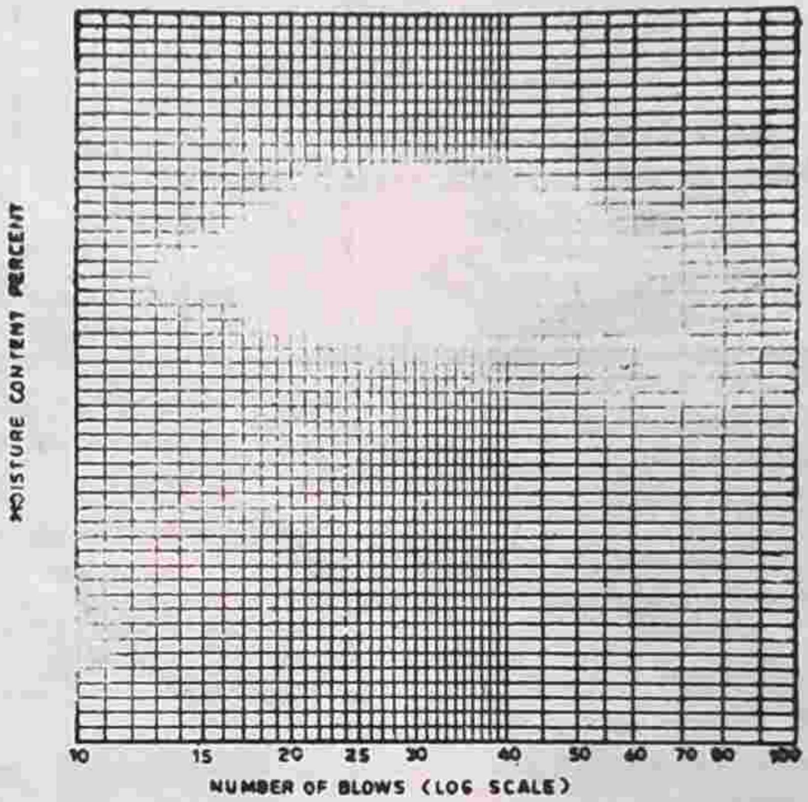
OBSERVATIONS AND CALCULATIONS

TABLE 3

(Semi Log Graph Paper)

Soil Sample No. Date

Flow Curve



Liquid Limit = Moisture Content at 25 Blows

(From the Graph)

Results

Liquid limit L.L. (%) =
Plastic limit P.L. (%) =
Plasticity Index P.I. =
Classification =
Flow Index I_F =
Toughness Index I_T =

EXPERIMENT No. 5

Shrinkage Factors Determination

Object

(a) To determine the shrinkage limit of a soil

(b) To calculate shrinkage factors

Theory and Applications

Shrinkage limit is the maximum water content at which a reduction in water content does not cause an appreciable decrease in volume of the soil mass. At shrinkage limit, on further reduction in water, air starts to enter into the voids of the soil and keeps the volume of voids constant.

In Figure 5.1 let (a) represent the initial soil sample in saturated state with initial mass W_1 and volume V_1; (c) represent the oven dry sample with mass W_s and volume V_2. According to definition, the water content at (b) will be the shrinkage limit.

Mass of water in (a) $= W_1 - W_s$

Loss in water from (a) to (b) $= (V_1 - V_2)\,\gamma_w$

$\therefore$ Mass of water in (b), W_s

$$= (W_1 - W_s) - (V_1 - V_2)\,\gamma_w$$

$\therefore$ Water content in (b), w

$$= \frac{(W_1 - W_s) - (V_1 - V_2)\,\gamma_w}{W_s} \qquad (5\text{-}1)$$

$\therefore$ Shrinkage limit, $w_{S.L.}$ (%)

$$= \left[w_1 - \frac{(V_1 - V_2)\,\gamma_w}{W_s} \right] \times 100 \qquad (5\text{-}2)$$

where w_1 = water content in (a)

Other shrinkage factors i.e. shrinkage ratio, volumetric shrinkage may also be calculated from the test data of shrinkage lsmit.

Shrinkage Ratio : It is the ratio of a given volume change expressed as a percentage of the dry volume to the corresponding change in water content above the shrinkage limit.

Volumetric Shrinkage : It is the decrease in volume of a soil mass when the water content is reduced from a given percentage to the shrinkage limit and which is expressed as percentage of dry volume of the soil mass.

Application

The value of shrinkage limit is used for understanding the swelling and shrinkage properties of cohesive soils. It is used for calculating the shrinkage factors which helps in the design problems of the structures made up of the soils or/and resting on soils. It gives an idea about the suitability of the soil as a construction material in foundations, roads, embankments and dams. It helps in knowing the state of the given soil. Approximate values of specific gravity of soil grains may also be determined from the data of shrinkage limit tests.

In Figure 5.1 specific gravity,

$$G_s - \frac{W_s}{V_s \times \gamma_w} \qquad (5\text{-}3)$$

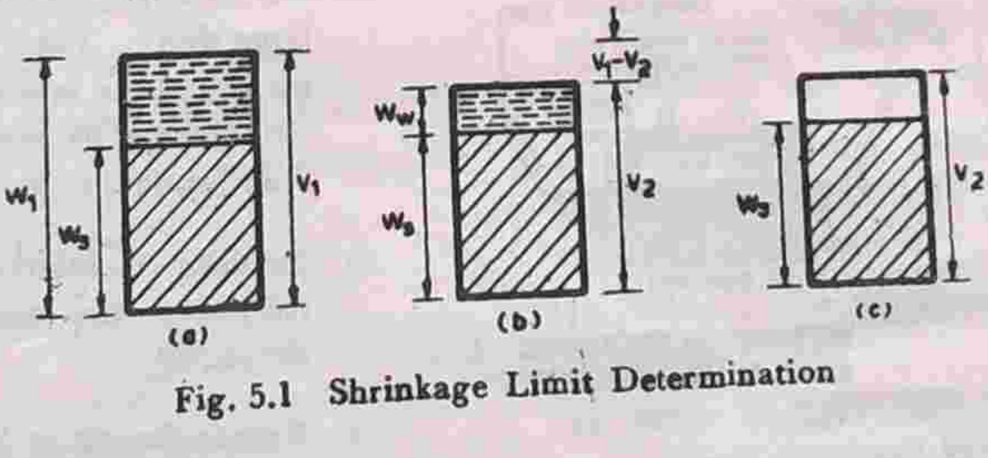


Fig. 5.1 Shrinkage Limit Determination

Where $$V_s = V_1 - \frac{W_1 - W_s}{\gamma_w} \quad (5\text{-}4)$$

$$\therefore G_s = \frac{W_s}{V_1 \gamma_w - (W_1 - W_s)} \quad (5\text{-}5)$$

Apparatus

Special

1. Three circular shrinkage dish (porecelain/stainless steel/brass with flat bottom about 4.5 cm in dia and 1.5 cm high).
2. Three porcelain evaporated dish (two about 12cm (large) and one 6cm (small) in diameter).
3. One glass plate with three prongs.
4. One plain glass plate (7.5 cm × 7.5 cm).
5. One glass or stainless steel cup, (about 5.0 cm in dia and 2.5 cm high with level and smooth ground top rim.
6. Mercury
7. 425 micron sieve.

General

1. Spatula
2. Straight edge
3. Oven
4. Desiccator
5. Balance (sensitivity 0.01 gm)

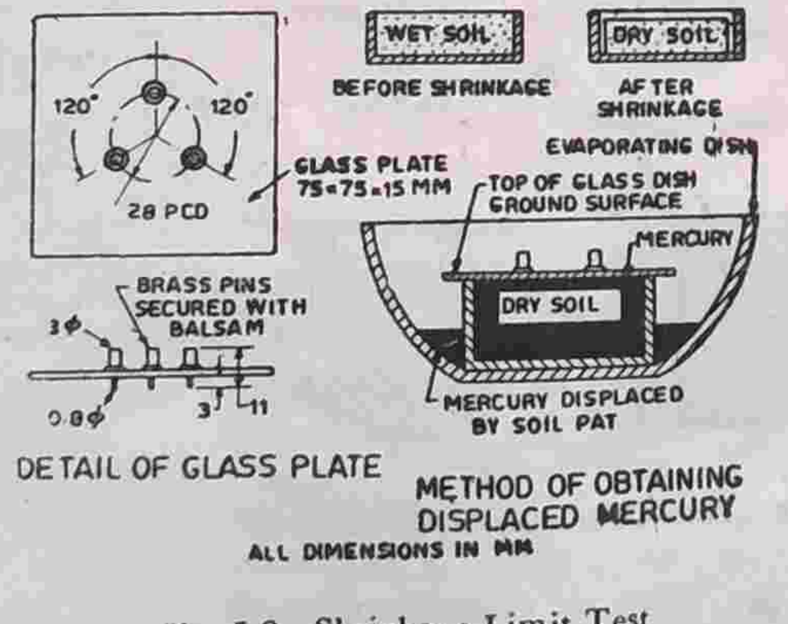


Fig. 5.2 Shrinkage Limit Test

Procedure

1. Mix about 30 gm of soil passing 425 micron sieve with distilled water. The water added should be sufficient to make the soil pasty enough to be readily worked into the shrinkage dish without inclusion of air bubbles.
2. Coat the inside of two shrinkage dish with a thin layer of vaseline. Place the soil sample in the dish, by giving gentle taps. Strike off the top surface with a straight edge.
3. Weigh the shrinkage dish immediately full of wet soil. Dry the dish first in air and then in an oven.
4. Weigh the shrinkage dish with dry soil pat.
5. Clean and dry the shrinkage dish and determine its empty mass.
6. Also weigh an empty porcelain dish (small size) which will be used for weighing mercury. This dish will be known as mercury weighing dish.
7. Keep the shrinkage dish in a large porcelain dish, fill it to overflowing with mercury and remove the excess by pressing the plain glass plate firmly over the top of the dish. Transfer the contents of the shrinkage dish to the mercury weighing dish and weigh.
8. Place the *glass* cup in a large dish. fill it to over-flowing with mercury, remove the excess by pressing the glass plate with three prongs firmly over the top of the cup.
9. Wipe the outside of the glass cup to remove any adhering mercury, then place it in another large dish. Place the dry soil pat on the surface of the mercury and submerge it under the mercury by pressing with the glass plate with prongs.
10. Transfer the mercury displaced by the dry syil pat to the mercury weighing dish and weigh.
11. Repeat the test at least three times for each soil sample.

Precautions

1. The water content of the soil taken in shrinkage dish should be above liquid limit but *within* 10% from liquid limit.
2. To prevent the cake from adhering to the shrinkage dish and consequent cracking of the dry soil pat, the inside of the shrinkage dish should be greased with vaseline.
3. During filling the shrinkage dish with soil paste, sufficient tapping should be done to remove the entraped air.
4. The dry soil pat should be weighed soon after it has been removed from a desiccator otherwise it picks up moisture from the air.
5. Test should be repeated at least three times for each soil sample and the average of the results thus obtained reported. If any individual value varies from the average by ± 2%, it should be discarded and the test repeated.
6. No air should be entrapped under the dry soil pat when pressing by the glass with prongs is being carried out.

Observations and Calculations

(a) Shrinkage Limit

1. Enter all the observations in the table.
2. Calculate the shrinkage limit using the equation (5-2).

$$w_{S.L.} = \left[w_1 - \frac{(V_1 - V_2)\,\gamma_w}{W_s}\right] \times 100$$

Where $w_{S.L.}$ = shrinkage limit in % soil pat.

w_1 = initial water content of wet soil pat.

V_1 = volume of wet soil pat in cc.

V_2 = volume of dry soil in cc.

W_s = mass of oven-dry soil pat in gm.

γ_w = mass density of water in g/cc.

(b) Other Shrinkage Factors

Shrinkage ratio

$$SR = \frac{W_s}{V_2} \times \frac{1}{\gamma_w} \qquad (5\text{-}6)$$

Where W_s = mass of oven dry pat in gm.

V_2 = volume of oven dry soil pat in cc

2. Volumetric shrinkage

$$VS = (w_1 - w_{S.L.}) \times SR \qquad (5\text{-}7)$$

Where w_1 = given moisture content in %

$w_{S.L.}$ = shrinkage limit in %

S.R. = shrinkage ratio

3. Linear shrinkage

$$L_s = 100\left[1 - \sqrt[3]{\frac{100}{VS+100}}\right] \qquad (5\text{-}8)$$

Where VS = volumetric shrinkage.

QUESTIONS

1. What is understood by shrinkage limit ?
2. Why does volume not decrease on reduction of water content at shrinkage limit ?
3. What is the degree of saturation at shrinkage limit ?
4. Does volume increase on addition of water content at shrinkage limit ?
5. Is shrinkage limit a natural or conventional soil index ? Is shrinkage limit a soil index for fine grained soil or coarse grained soils or all type of soils ?
6. Is shrinkage limit a constant or variable soil index for one type of soil ? Explain.
7. What are the factors affecting the value of shrinkage limit ?
8. Gan shrinkage limit be equal or more than its plastic and liquid limit ? Explain.
9. Can shrinkage limit be equal or more than its natural moisture content ? What normal values of shrinkage limit do you expect.
10. What do you understand by shrinkage ratio, volumetric shrinkage and linear shrinkage ?
11. Derive an expression for shrinkage limit.
12. Do you know any relationship between shrinkage limit, probable expansion and degree of expansion ?
13. What is the consistency of soil at shrinkage limit ?
14. What changes in the soil behaviour do take place at shrinkage limit ?

15. If there are two soils A and B with the following results :

	A	B
Liquid limit	60%	60%
Plastic limit	40%	30%
Shrinkage limit	20%	10%
Natural water content	16%	16%

(i) Determine the consistency of soils at their natural water contents.

(ii) Explain the swelling and shrinkage behaviour of the two soils on wetting and drying.

16. What are the practical application of shrinkage factors ?

17. If air bubble is left during filling the wet soil in the shrinkage dish, what is its effect on shrinkage limit ?

18. Why do you coat the inside of the shrinkage dish with vaseline.

19. If dry pat picks up some moisture from the air before weighing it, what is the effect on the value of shrinkage limit ?

20. Why does the glass plate have three prongs ?

21. Is it necessary to use only mercury in this test ? Why ?

22. What type of sample (undisturbed or remoulded) is used in this test ?

23. If remoulded samples are used, would you prefer oven dried sample or air dried sample. What difference in the values do you expect ?

24. Hew the approximate value of specific gravity of soil particles is obtained by shrinkage limit test data ?

DISCUSSIONS

EXPERIRMENT No. 5

SHRINKAGE FACTORS

OBSERVATIONS AND CALCULATIONS

Determination No.		1	2	3
(1) Shrinkage dish No.				
(2) Mass of dish + wet soil pat	(gm)			
(3) Mass of dish + dry soil pat	(gm)			
(4) Mass of water, (2) − (3)	(gm)			
(5) Mass shrinkage dish empty	(gm)			
(6) Mass of dry soil pat $(W_s) = (3) - (5)$	(gm)			
(7) Initial water content $(w_1) = \frac{(4)}{(5)} \times 100$	(%)			
(8) Mess of weighing dish + mercury (filling shrinkage dish)	(gm)			
(9) Mass of weighing dish empty	(gm)			
(10) Mass of mercury (8) − (9)	(gm)			
(11) Vol. wet soil pat $(V_1) = \frac{(10)}{13.6}$	(cc)			
(12) Mass of weighing dish + displaced mercury (by dry pat)	(gm)			
(13) Mass of mercury displaced (12) − (9)	(gm)			
(14) Vol. dry soil pat $(V_2) = \frac{(13)}{13.6}$	(cc)			

Results

Shrinkage limit, $w_{S.L.} = \left(w_1 - \frac{V_1 - V_2}{W_s}\right) \times 100$ (%)

Shrinkage ratio $SR = \frac{W_s}{\gamma_w V_2} = \frac{(6)}{(14)}$

Volumetric shrinkage $VS = (w_1 - w_{S.L.})\, SR$ (%)

Linear shrinkage $L_s = 100 \left[1 - \sqrt[3]{\frac{100}{VS + 100}}\right]$

EXPERIMENT NO. 6

Specific Gravity Test

Object

To determine the specific gravity of the soil particles passing 4.75 mm I. S. Sieve using pycnometer.

Theory and Applications

Specific gravity is the ratio of the mass/weight in air of a given volume of dry soil solids to the mass/weight of equal volume of distilled water at 4°C.

In Fig. 6-1 let (a) represent the empty pycnometer of mass = W_1

(b) represent the pycnometer + soil grains of mass = W_2

(c) represent the pycnometer + soil grains + water of mass = W_3

(d) represents the pycnometer + water of mass = W_4

$\therefore$ Mass of soil grains $W_s = W_2 - W_1$

Mass of equal volume of distilled water

$$= (W_4 + W_2 - W_1 - W_3)$$

Specific gravity of soil grains

$$= \frac{W_2 - W_1}{(W_2 - W_1) - (W_3 - W_4)} \qquad \text{(6-1 A)}$$

$$= \frac{W_s}{W_s + W_4 - W_3} \qquad \text{(6-1 B)}$$

The value of specific gravity depends upon temperature, hence its value is reported at standard temperature of 27°C.

$$G_s \text{ (at 27°C)} = G_s \text{ (at } T_t\text{°C)}$$

$$+ \frac{\text{Specific gravity of water at } T_t\text{°C}}{\text{Specific gravity of water at 27°C}} \qquad \text{(6-2)}$$

Applications

Specific gravity of soil grains is a important property and is used in calculating void ratio, porosity, degree of saturation if density and water content are known.

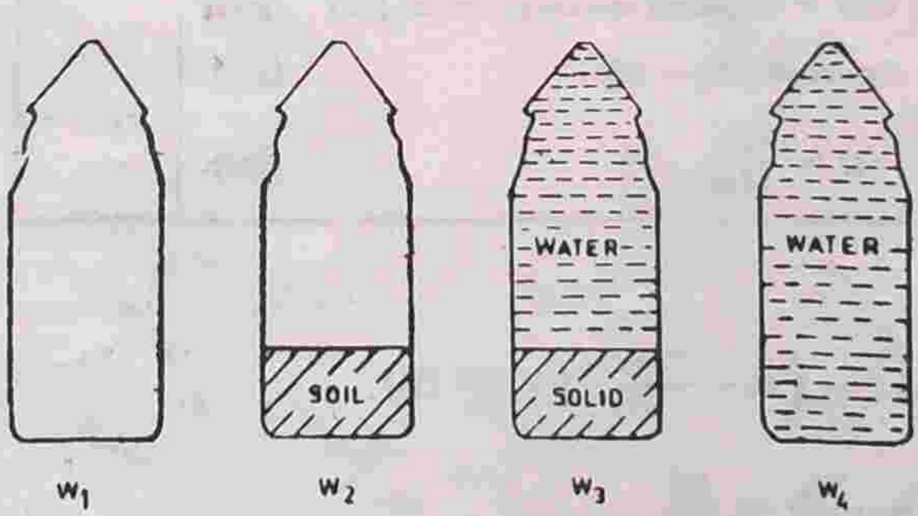
$$\text{Void ratio, } e = \frac{G_s(1 + w_w)}{\gamma_t}\gamma_w - 1 \qquad \text{(6-3)}$$

Where e = void ratio

G_s = specific gravity

w_w = water content

γ_w = mass density of water (g/cc)



(a) (b) (c) (d)

Fig. 6.1 Specific Gravity Determination by Pycnometer

γ_t = moist density of soil (g/cc)

and degree of saturation, $S = \frac{G_s \times W}{e} \times 100$ (6-4

Where S = degree of structure (%)

G_s = specific gravity of soil grains

w = water content

e = void ratio

Its value helps upto some extent in identification and classification of soils. It gives an idea about the suitability of the soil as a construction material, higher value of specific gravity gives more strength for roads and foundations. It is used in computing the soil particle size by means of hydrometer analysis. It is also used in estimating the critical hydraulic gradient in soil when a sand boiling condition is being studied and in zero air-void calculations in the compaction theory of soils.

Its value ranges as follows :

Coarse grained soils	2.6—2.7
Fine grained soil	2 7—2 8
Organic soil	2.3—2.5

Apparatus

Special

1. Pycnometer
2. 4.75 mm (or 2 mm) I.S. Sieve

General

1. Vacuum pump (or hot water bath)
2. Balance (accuracy 0.1 gm)
3. Drying oven
4. Desiccator
5. Glass rod
6. Distilled and deaired water
7. Thermometer (0 to 50°C)

Procedure

1. Dry the pycnometer thoroughly and weigh with its cap tightly screwed on.
2. Mark the cap and pycnometer with a vertical line parallel to the axis of the pycnometer so that each time the cap is screwed the same amount.
3. Unscrew the cap and put in about 200 gm of oven dried soil[a] passing 4.75 mm I.S. Sieve[b] and weigh again.
4. Add sufficient deaired water to cover the soil about half full and screw on the cap.
5. Shake well and connect to the vacuum pump to remove entrapped air.
6. Allow the air to be evacuated for at least 20 minutes for fine grained soil or 10 minutes for sandy soils. Shake the pycnometer occasionally to assist in the air evacuation.
7. After the entrapped air has been largely removed, disconnect the pump and fill the pycnometer with water about three fourth full.
8. Reapply the vaccum for at least 5 minutes. Evacuation should be continued until very few bubbles appear on the top of the water.
9. After the air has been eliminated, fill the pycnometer with water completely upto the mark.
10. Thoroughly dry the pycnometer from the outside and weigh it.
11. Record the temperature of the content in degree centigrade.
12. Clean the pycnometer by washing water thoroughly.
13. Fill the pycnometer with water upto its top and screw on the cap.
14. Weigh the pycnometer after drying it on the outside thoroughly.
15. Repeat the test twice more.

Notes (a) Specimens containing natural moisture may also be taken, but oven dry mass or the soil must be determined at the end of test.

(b) (i) 4.75 mm sieve is used to determine specific gravity of sand silty or clayey soil.

(ii) 2 mm sieve is used if the value of specific gravity is used in connection with hydrometer analysis.

Precautions

1. The soil grains whose specific gravity is to be determined should be completely dry.

2. Dried soil taken for testing should have the soil grains of its original size, so if on drying soil humps are formed, they should be broken to its original size.

3. Hold the rubber tubing tightly with the pycnometer so that there is no leakage when vacuum pump works.

4. Inaccuracies in weighing and failure to completely eliminate the entrapped air are the main sources of error. Both should be avoided by careful working.

5. Cap should be screwed upto the same mark during the test.

6. Cap should be properly screwed with washer to avoid any leakage.

Observations and Calculations

(a) Determine the specific gravity of soil grains using equation (6-1 A).

$$(G_s) = \frac{(W_2-W_1)}{(W_2-W_1)-(W_3-W_4)}$$

(b) Calculate the correction factor C_t.

$$(C_t) = \frac{\text{Relative density of water at } T_t°C}{\text{Relative density of water at } 27°C}$$

(c) Calculate the specific gravity at 27°C

$$(G_s)_{27°C} = (G_s)_{Tt} \times C_t$$

(d) The average of three values of the same soil sample is taken and reported to the nearest 0.01. If any of the values differs by more than 0.03 from the average, that test is discarded and other test is done.

QUESTIONS

1. What do you understand by specific gravity of soil grains ?

2. What is the difference between the specific gravity of soil grains and soils ?

3. Derive an expression for specific gravity of soil grains for laboratory determination.

4. What are normal ranges of specific gravity for gravel, sand, silt, clay and organic soils ?

5. What are the relationships between void ratio, degree of saturation and specific gravity of soil grains ?

6. How do you calculate the critical gradient with the help of specific gravity value ?

7. What is the effect of temperature on the specific gravity ?

8. What is the standard temperature at which the value of specific gravity is determined ?

9. How and where does the specific gravity value help in studying the consolidation properties of clays ?

10. What is the difference between density of soil and specific gravity of soil grains ?

11. What are the units of density and specific gravity of soil grains in MKS system of unit ?

12. How do you use the value of specific gravity in knowing the size of soil grains by hydrometer analysis.

13. What is the relationship between dry density of soil at zero air voids, specific gravity of soil grains and water content ?

14. What are the field applications of specific gravity of soil grains ?

15. Can you use any other liquid instead of water in this test ? If yes, name that liquid.

16. If you use a liquid other than water, what modifications in the expression of specific gravity will be made ?

17. Can you use this test to determine the moisture content of the soils ? Explain.

18. If specific gravity of soil particles retained on 4.75 m.m. I.S. sieve is to be determined, what changes in the procedure do you expect ?

19. During the test, if air is not completely removed, what is the effect on the value of specific gravity ?

20. If soil taken for test is not completely dry, what is the effect on the value of specific gravity ?

21. What precautions do you take during this test.

22. What are the other methods to determine the specific gravity of soil grains ?

DISCUSSIONS

EXPERIMENT No. 6

SPECIFIC GRAVITY

OBSERVATIONS AND CALCULATIONS

Date

Soil Sample No.

(i) Test temperature T_t, °C =

(ii) Relative density of water at T_t, °C =

(iii) Relative density of water at 27°C =

(iv) Correction factor due to temp., C_t =

Determination No.	1	2	3
(1) Pycnometer/Bottle No.			
(2) Mass of Pycnometer W_1 (gm)			
(3) Mass of Pycnometer + dry soil, W_2 (gm)			
(4) Mass of Pycnometer + Soil + Water, W_3 (gm)			
(5) Mass of Pycnometer + Water, W_4 (gm)			
(6) Specific gravity of soil at T_t °C			
(7) Specific gravity of soil at 27°C = (6) × C_t			

Results

Specific gravity of soil grains at 27°C =

EXPERIMENT No. 7

Permeability Tests

Object

To determine coefficient of permeability of given soil sample at desired density by a suitable method.

Theory and Applications

The property of the soils which permits water (fluids) to percolate through its continuously connected voids is called its permeability.

Depending upon the value of Reynold's number, the flow of water through soils may be 'laminar' or 'turbulent'. In laminar flow, a particle of water starting from a given position follows a definite path without criscrossing the path of other particles. In turbulent flows the particles do not follow any definite path but have random, twisting and criscrossing path.

For laminar and steady flow, according to Darcy's law the rate of flow of water is proportional to the hydraulic gradient in uniform and homogeneous soils.

i.e. $$v \propto i \qquad (7\text{-}1)$$

where v = discharge velocity of water

$\therefore$ $v = ki$

If q = discharge of water per unit time

$$q = kiA \qquad (7\text{-}2)$$

If $i = 1$

$$k = v \qquad (7\text{-}3)$$

where i = hydraulic gradient

k = coefficient of permeability

A = cross sectional area of the soil for discharge q.

In soil mechanics, the coefficient of permeability, k expresses the degree of permeability. It has the velocity dimensions.

Factors affecting the coefficient of permeability can be studied by the equation

$$k = C\, d_s^2 \frac{\gamma_w}{\eta} \frac{e^3}{1+e} \qquad (7\text{-}4)$$

where k = coefficient of permeability

C = constant

d_s = average diameter of soil grains

γ_w = unit weight of water

η = viscosity of the water

e = void ratio of the soil

Viscosity and unit weight of water depend upon temperature, hence the coefficient of permeability is effected by the climatic conditions also. Constant 'C' depends upon arrangement and shape of grains and voids. Thus the soil in-situ often as smaller permeability in vertical direction as compared to the horizontal due to horizontally stratified structure.

The coefficient of permeability may be determined both in the laboratory and field by direct tests. In the laboratory, constant head method is more suited to coarse grained soils as the quantity of seepage in case of relatively impervious soils is less. Variable head method is suited to fine grained soil as the fall of head is very fast in coarse grained soils.

Applications

Water flowing through soil exerts considerable seepage forces which has direct effect on the safety of hydraulic structures.

The rate of settlement of compressible clay layer under load depends on its permeability. The quantity of stored water escaping through and beneath an earthen dam depends on the permeability of the embankment and the foundations respectively. The rate of drainage of water through wells and excavated foundation pits depends on the coefficient of permeability of the soils. Shear strength of soils also depends indirectly on its permeability, because dissipation of pore pressure is controlled by its permeability. Rough values of coefficient of permeability for different types of soils are given in Table 7.1.

TABLE 7.1

Type of soil	Value of k (cm/sec)
Gravel	$10^3 - 1.0$
Sand	$1.0 - 10^{-3}$
Silt	$10^{-3} - 10^{-6}$
Clay	Less than 10^{-6}

According to U.S. Bureau of Reclamation, soils are classified as follows :

Impervious	k less than 10^{-6} cm/sec.
Semipervious	k between 10^{-6} to 10^{-4} cm/sec
Pervious	k greater than 10^{-4} cm/sec

Apparatus

Special

1. Permeameter mould (internal dia=100 m.m.[a], effective height = 127.3 m.m., capacity 1000 c.c.) (common)
2. Accessories of the permeameter (cover, base, detachable collar, porous stones, dummy plate) (common)
3. Round filter paper 100 mm. dia. (common)
4. A static or dynamic compaction device (if remoulded samples are used) (common)
5. Constant head reservoir (common)
6. Graduated glass stand pipe (internal dia 5 to 20 mm, preferably 10 mm) (variable head)
7. Support frame and clamps (variable head)
8. Funnel (variable head)
9. Measuring flask (constant head)

General (common to both the methods)

1. Metre scale
2. Balance (accuracy 0.5 gm)
3. Stop watch
4. Thermometer (accuracy 0.1 °C)
5. Deaired water
6. Drying oven
7. IS : Sieve 4.75 mm (if remoulded samples are (used)
8. Grease
9. Straight edge
10. Drying crucibles
11. Desiccator

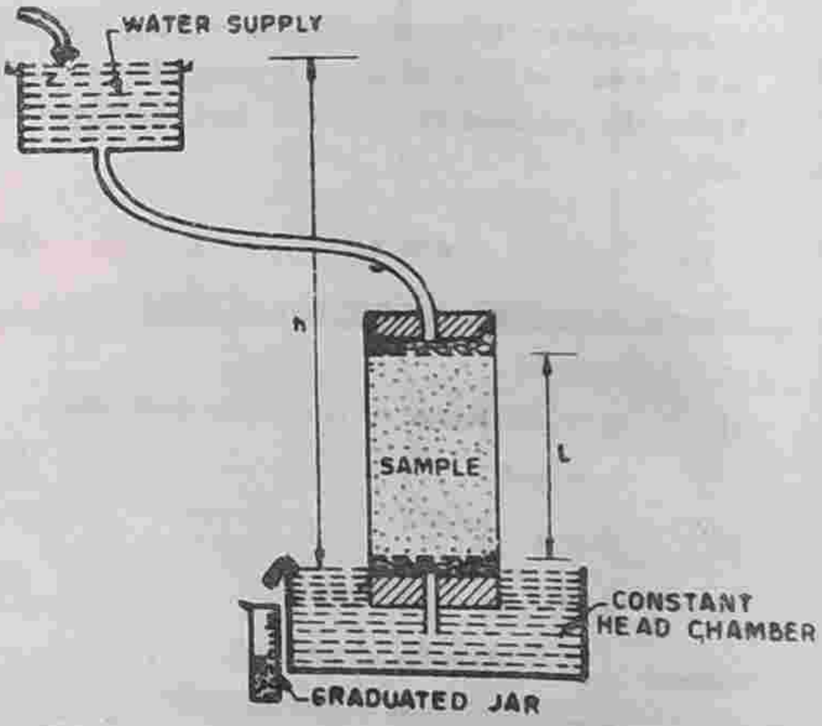


Fig. 7.1 Constant Head Permeameter

Note :—(a) According to I.S. Specifications, the maximum size of soil particle which can be tested with mould is 10 mm. In authors opinion the maximum size for this mould is the passing of 4.75 mm I.S. Sieve.

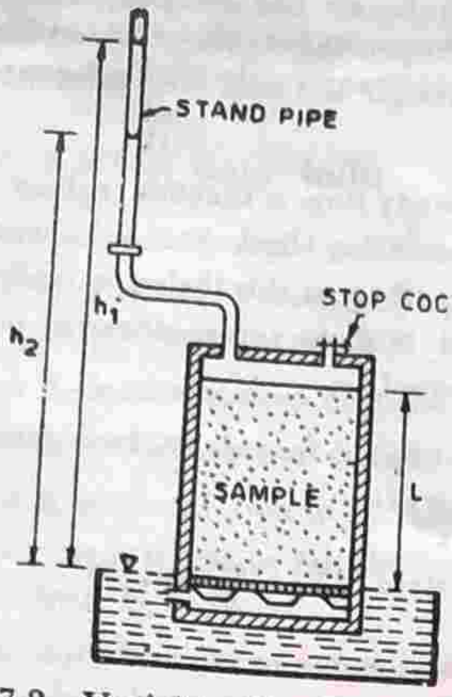


Fig 7.2 Variable Head Permeameter

Procedure

A. Variable Head Method

1. Remove the cover of the mould and apply a little grease on the sides of the mould.
2. Weigh the mould with dummy plate.
3. Measure the internal diameter and effective height of the mould, then attach the collar and the base plate.
4. (i) Compact the soil at given dry density and moisture content by a suitable static or dynamic device[b] for remoulded samples.

   (ii) For undisturbed samples, trim off the undisturbed specimen in the form of a cylinder about 85 mm in diameter and height equal to that of mould. Place the specimen centrally over the bottom porous disc and filter paper.

   Fill the annular space between the mould and the specimen with an impervious material such as cement slury or bentonite slurry to provide sealing against leakage from the sides.
5. Remove the collar and base plate, trim off the excess soil and level with the top of the mould.
6. Clean the outside of the mould and dummy plate.
7. Weigh the mould with soil and dummy plate. Difference of this mass and the mass taken in step 2 will give the mass of soil used.
8. Apply grease around the porous stone and base plate, put the porous stone inside the base plate and filter paper on porous stone.
9. Remove the dummy plate and place the mould with washer on the base plate.
10. Put the small quantity of the soil sample in drying oven to determine the moisture content.
11. Clean the edges of the mould and the collar and apply grease in the grooves around them.
12. Place a filter paper, porous stone and washer on the top of the soil sample and fix up the collar again.
13. Connect the reservoir with water to the outlet at the bottom of the mould and allow the water to flow in. Wait till the water has been able to travel up and saturate the sample[c] Allow about one cm depth of free water to collect on the top of the sample.

Note :—(b) Static compaction device is more convenient and accurate to compact the soils at any given density and moisture content. Dynamic compaction is effective to compact the soil to maximum dry density at optimum moisture content.

(c) Soils of low permeability require flow under a high head for periods ranging from a day to a week depending upon the permeability and the head. Alternatively, the specimen may be subjected to a gradually increasing vacuum with bottom outlet closed so as to remove air from the soil voids. The vacuum may be increased to at least 70 cm of mercury which may be maintained for 15 minutes or more depending upon the soil type. The excavation is followed by a very slow saturation of the specimen with deaired water from the bottom upwards under full vacuum.

14. Fill the remaining portion of the cylinder with deaired water without disturbing the surface of the soil.

15. Fix the cover plate over the collar and tighteen the nuts in the rods.

16. Disconnect the reservoir from the outlet at the bottom and connect the stand pipe to the inlet at the top plate. Fill the stand pipe with water.

17. Open the stop cock at the top and allow water to flow out so that all the air in the cylinder is removed.

18. Fix the height h_1 and h_2 on the pipe from the centre of the outlet such that (h_1-h_2) is about 30 to 40 cm. Mark the level of $\sqrt{h_1 h_2}$ from the centre of the outlet.

19. When all the air has escaped, close the stop cock and allow the water from the pipe to flow through the soil and establish a steedy flow.

20. Record the time intervals for the head to fall from h_1 to $\sqrt{h_1 h_2}$ and from $\sqrt{h_1 h_2}$ to h_2. The time intervals should be same, otherwise steady flow is established.

21. Change the height h_1 and h_2 and record the time intervals.

22. Stop the flow of water, disconnect all parts.

23. Take a small quantity of the soil sample from the mould in the drying crucible and put inside the drying oven for moisture content determination.

24. Measure the temperature of the water.

B. Constant Head Method

1. Take steps 1 to 16.

2. Disconnect the reservoirs from the outlet as the bottom and connect to the inlet at the top plate.

3. Open stop cock at the cover and allow water to flow out so that all the air in the cylinder is removed.

4. When all the air has escaped, close the stop cock and open the outlet. Allow the water to flow through the soil and establish a steady flow.

5. When steady flow is reached, collect the water in a measuring flask for a convenient time interval. Repeat this thrice, quantity of water collected must be same, otherwise observations are repeated.

6. Repeat step (v) for atleast two more different time intervals.

7. Repeat steps (22), (23) and (24).

Precautions

1. All the possibilities of leakage at the joints must be eliminated. All the joints and washer must be thoroughly cleaned so that there are no soil particles between them.

2. Apply the grease liberally between mould, base plate and collar.

3. Rubber washers must be moistured with water before placing.

4. Porous stones must be saturated just before placing.

5. Deaired and distilled water must be used to avoid the choking of flow water.

6. Soil samples must be fully saturated before taking the observations

7. In order to ensure laminar flow condition, cohesionless soils must be tested under low hydraulic gradient.

8. Steady flow must be established before taking the observations.

9. In constant head method, quantity of water collected must be sufficient and measured very accurately to eliminate large errors.

Observations and Calculations

(a) Enter all observations of variable head method in table 2 and of constant head method in table 3.

(b) Calculate the coefficient of permeability of the soil using the following equations.

$$k_T = 2.303 \frac{aL}{At} \log_{10} h_1/h_2 \quad (7\text{-}5)$$

(variable head method).

where k_T = coefficient of permeability at test temperature T°C (cm/sec)

a = X-Sectional area of stand pipe (cm^2)

L = effective length of sample (cm)

A = X-sectional area of sample (cm^2)

t = time interval to fall the head from h_1 to h_2 (sec)

h_1 = initial height of water in the pipe above the outlet (cm)

h_2 = final height of water in the pipe above the outlet (cm)

$$k_T = \frac{Q}{At}\ \frac{L}{h} \quad \text{(constant head method).} \quad (7\text{-}6)$$

Where k_T = coefficient of permeability at test temperature T°C (cm/sec)

Q = quantity of water collected in time t (ml)

A = cross-sectional area of the soil sample (cm^2)

L = length of the soil sample (cm)

h = constant hydraulic head (cm)

(c) Report the coefficient of permeability at standard temperature 27°C.

$$k_{27} = k_T \times \frac{\eta_T}{\eta_{27}} \quad (7\text{-}7)$$

Where k_{27} = coefficient of permeabilty at 27°C

k_T = coefficient of permeability at T°C

η_T = coefficient of viscosity at T°C (See Appendix).

η_{27} = coefficient of viscosity at 27°C

(d) Calculate the density, void ratio and degree of saturation at which test is performed.

$$\text{Void ratio, } e = \frac{G_s}{\gamma_d} - 1 \quad (7\text{-}8)$$

Where G_s = specific gravity of soil grains (assume 2.65 if not known)

γ_d = dry density of the soil sample (g/cc)

$$\text{Degree of saturation, } S = \frac{w \times G_s}{e} \quad (7\text{-}9)$$

Where w = moisture content in %

QUESTIONS

1. What is understood by permeability and coefficient of permeability of soils ?
2. What do you understand by flow velocity and discharge velocity of water through soils ?
3. What is Darcy's law of flow through soils ? What are its limitations ?
4. What are laminar and turbulent flows ? How do you differentiate between the two ?
5. What type of flow do you expect in soils ?
6. What are steady and unsteady flow of water ? What type of flow does occur in soils ? Why ?
7. If a soil is permeable, do you think flow of water is bound to take place through it ?
8. Is coefficient of permeability a constant or variable for one sort of soil ?
9. For homogenous soils, does coefficient of permeability depend upon direction of flow ?
10. What is the effect of density and porosity of soils on the coefficient of permeability ?
11. What is the effect of size and shape of soil particles on the coefficient of permeability ?
12. If there are two soils A and B with following properties, compare their coefficient of permeability :

	Soil A	Soil B
Void ratio	0.4	0.8
Grain size	2 m.m.	1 m.m.

13. What is the effect of density of soil and temperature of water on the coefficient of permeability ?
14. How is the value of average coefficient of permeability evaluated in a stratified deposit if the flow were (i) parallel and (ii) perpendi-

cular to bedding planes? Which value is greater?

15. What is the unit of coefficient of permeability? What is the range of its values of gravel, sand silt and clay?

16. What are the field applications of coefficient of permeability of soils?

17. What are the laboratory methods to determine the coefficient of permeability of soils? Which method did you use? Explain.

18. What is the effect of entrapped air in the voids of soils on the coefficient of permeability? How do you ensure the removal of this air during your experiment?

19. What type of sample (undisturbed/compacted) did you use to determine the coefficient of permeability? Explain.

20. What is the size of permeameter with its accessories and soil sample used by you?

21. Is there any effect of size and shape of sample and head of water on the coefficient of permeability?

22. What is the coefficient of permeability of drainage base and drainage cap? Does it have any relation with the permeability of soil?

23. What are the important precautions to be taken in this test?

24. What are the indirect methods to determine the coefficient of permeability of soils? What are their limitations.

DISCUSSIONS

EXPERIMENT No. 7

PERMEABILITY

OBSERVATIONS AND CALCULATIONS

Soil Sample No. Date

TABLE 1

(i) Length of sample, L (cm) =

(ii) Diameter of sample, d (cm) =

(iii) Area of sample, A (cm^2) =

(iv) Mass of mould + dummy plate, W_1 (gm) =

(v) Mass of mould + soil + dummy plate, W_2 (gm) =

(vi) Mass of soil, $W = (W_2 - W_1)$ (gm) =

(vii) Volume of soil sample, V (cm^3) =

(viii) Density of soil sample, $\gamma_t = \frac{W}{V}$ (g/cc) =

(ix) Moisture content at the start, w_1 =

(x) Dry density of soil sample, $\gamma_d = \frac{\gamma_t}{1+w_1}$ (g/cc) =

(xi) Void ratio, $e = \frac{G_s}{\gamma_d} - 1$ =

Determination No.		At the start (before saturation)			At the end (after saturation)		
		1	2	3	1	2	3
(1) Container No:							
(2) Mass of container + wet soil	(gm)						
(3) Mass of container + dry soil	(gm)						
(4) Mass of container	(gm)						
(5) Mass of dry soil, (3)−(4)	(gm)						
(6) Mass of water, (2)−(3)	(gm)						
(7) Water content, $w = \frac{(6)}{(5)} \times 100$	(%)						
(8) Degree of saturation $= \frac{w\,G_s}{e}$	(%)						

EXPERIMENT No. 7

PERMEABILITY

OBSERVATIONS AND CALCULATIONS

TABLE 2

Soil sample No. (Variable Head Method) Date

(i) Diameter of stand pipe (cm) =

(ii) Cross sectional area of stand pipe, a (cm^2) =

(iii) Temperature of water, T (°C) =

(iv) Correction factor due to temperature, $C_t = \frac{\eta_T}{\eta_{27}}$ =

(v) Constant factor $\frac{2.303\ a\ L}{A}$ =

Determination No.	1	2	3
(1) Initial head, h_1 (cm)			
(2) Final head, h_2 (cm)			
(3) Head, $\sqrt{(h_1 h_2)}$ (cm)			
(4) Time interval (sec)			
(a) From h_1 to $\sqrt{(h_1 h_2)}$			
(b) From $\sqrt{(h_1 h_2)}$ to h_2			
(c) From h_1 to h_2, t = (a) + (b)			
(5) $\log_{10} h_1/h_2$			
(6) Coefficient of permeability, k (cm/sec) at test temperature T°C = $\frac{(v) \times (5)}{(4c)}$			
(7) Coefficient of permeability, k (cm/sec) at temperature 27°C = (6) × (iv)			

Results

Average value of coefficient of permeability at test temperature, k_T. =

Average value of coefficient of permeability at standard temperature 27°C k_{27}. =

Void ratio of soil sample e, =

Type of soil =

EXPERIMENT No. 7

PERMEABILITY

OBSERVATIONS AND CALCULATIONS

TABLE 3

Soil Sample No. (Constant Head Method) Date

Determination No.		1	2	3
(1) Hydraulic head, h	(cm)			
(2) Time interval, t	(sec)			
(3) Quantity of flow, Q	(ml)			
(a) I test for time, t	(ml)			
(b) II test for the same time, t	(ml)			
(c) III test for the same time, t	(ml)			
(4) Average quantity of flow, $\frac{(a+b+c)}{3}$	(ml)			
(5) Coefficient of permeability, k_T (at temperature T°)	(cm/sec)			
(6) Coefficient of permeability k_{27} (at temperature 27°)	(cm/sec)			

Results

Average value of coefficient of permeability at test temperature, k_T =

Average value of coefficient of permeability at standard temperature 27°C, k_{27} =

Void ratio of soil sample e, =

Type of soil =

EXPERIMENT No. 8

Compaction Test

Object

1. To determine the optimum moisture content and maximum dry density of a soil by proctor test.
2. To plot the curve of zero air void.

Theory and Applications

Compaction is the process of densification of soil mass by reducing air voids. This process should not be confused with consolidation which is also a process of densification of soil mass but by the expulsion of water under the action of continuously acting static load over a long period.

The degree of compaction of a soil is measured in terms of its dry density. The degree of compaction mainly depends upon its moisture content, compaction energy and type of soil. For a given compaction energy every soil attains the maximum dry density at a particular water content which is known as optimum moisture content.

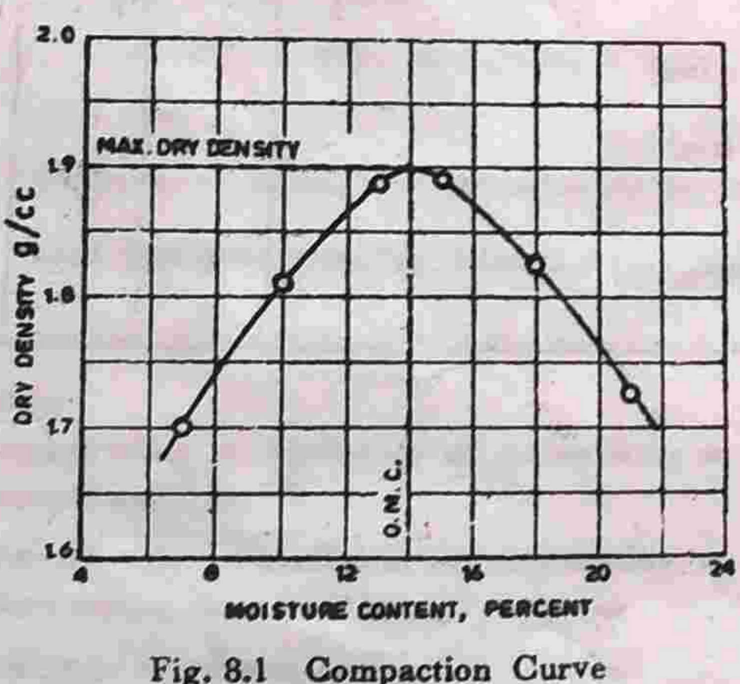


Fig. 8.1 Compaction Curve

In the dry side, water acts as a lubricant and helps in the closer packing of soil grains. In the wet side, water starts to occupy the space of soil grains and hinders in the closer packing of grains.

Application

Compaction of soils increase their density, shear stregth, bearing capacity but reduces their void ratio, porosity, permeability and settlements. The results of this test are useful in the stability of field problems like earthen dams, embankments, roads and airfields. In such constructions, the soils are compacted. The moisture content at which the soils are compacted in the field is controlled by the value of optimum moisture content determined by the laboratory proctor compaction test. The compaction energy to be given by the field compaction unit is also controlled by the maximum dry density determined in the laboratory. In other words, the laboratory compaction tests results are used to write the compaction specification for field compaction of soils.

Apparatus

Special :

1. Cylindrical mould (capacity 1000 c.c., internal dia 100 m.m., effective height 127.3 m.m.)

   or

   Cylindrical mould (capacity 2250 c.c., internal diameter 150m.m. effective height 127.30m.m.)
2. Rammer for light compaction (face diameter 50 m.m., mass of 2.6 kg, free drop 310 m.m.)

   or

   Rammer for heavy compaction (face diameter 50 m.m., mass 4.89 kg, free drop 450 m.m.)

3. Mould accessories (detachable base plate, removable collar).
4. I.S. Sieves (20 mm, 4.75 mm)

General

1. Balance (capacity 10 kg, sensitivity 1 gm)
2. Balance (capacity 200 gm sensitivity .01 gm)
3. Drying oven (temperature 105°C to 11°C)
4. Desiccator
5. Drying crucibles
6. Graduated jars
7. Straight edge
8. Large mixing pan
9. Spatula
10. Scoop

Procedure

1. Take about 20 kg for 1000 cc mould or 45 kg for 2250 cc mould of air dried and mixed soil.
2. Sieve this soil through 20 mm and 4.75 mm sieves.
3. Calculate the percentage retained on 20 mm and 4.75 mm sieves and passing from 4.75 mm sieve. Do not use the soil retained on 20 mm sieve.
4. Use a mould of 10 cm diameter if percentage retained on 4.75 mm sieve is less than 20 or use a mould of 15 cm diameter if percentage retained on 4.75 mm sieve is more than 20.
5. Mix the soil retained on 4.75 mm sieve and passing from 4.75 mm sieve thoroughly in the proportion obtained in step 3.
6. Take about 2.5 kg of the soil for 1000 cc mould or 6 kg for 2250 cc mould for light compaction. Or take about 2.8 kg of the soil for 1000 cc mould or 6.5 kg for 2250 cc mould for heavy compaction.
7. Add water to it to bring its moisture content to about 4% in coarse grained soils and 8% in fine grained soils.
8. Clean, dry and grease lightly the mould and base plate. Weigh the mould with base plate.
9. Fit the collar and place the mould on a solid base.
10. *For light compaction*, compact the wet soil in three equal layers by the rammer of mass 2.6 kg and free fall 31 cm with 25 evenly distributed blows in each layer for 10 cm diameter mould and 56 blows for 15 cm diameter mould. Alternatively *for heavy compaction*, compact the soils using the rammer of mass 4.89 kg and free fall 45 cm in five layers, each layer being given 25 blows for 10 cm diameter mould and 56 blows for 15 cm diameter mould.
11. Remove the collar and trim off the soil flush with the top of the mould. In removing the

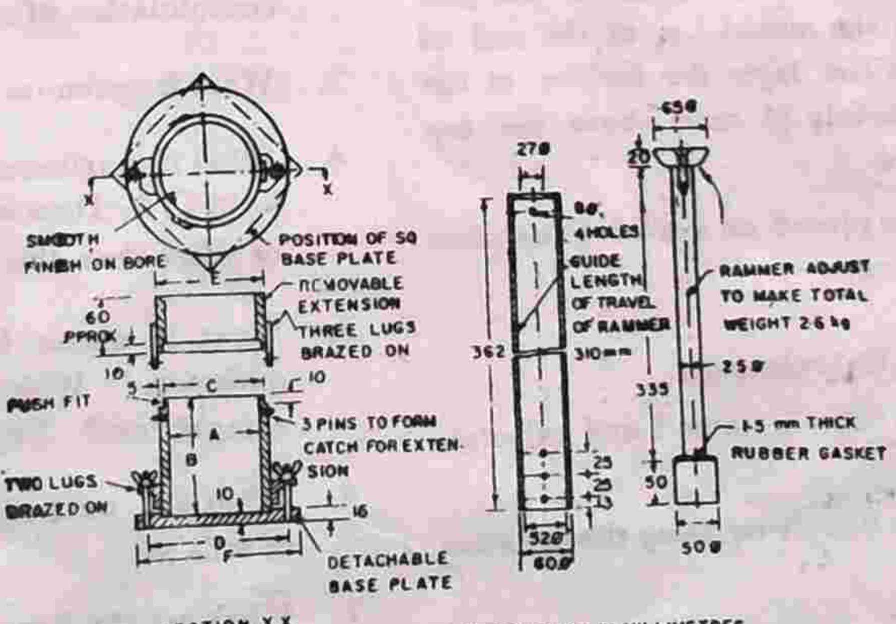


Fig. 8.2 Dimensional Apparatus for compaction

collar rotate it to break the bond between it and the soil before lifting it off the mould.

12. Clean the outside of the mould and base place, weigh the mould with soil and base plate.

13. Remove the soil from the mould and obtain a representative soil sample from the bottom, middle and top for water content determination.

14. Weigh the drying crucible with samples and put in the drying oven at temperature 105°C to 110°C for 24 hours.

15. Repeat the above procedure with 7; 10, 13, 16, 19 and 22% of water contents on coarse grained fresh soil samples and 11, 14, 17, 20 23 and 26% of water contents on fine grained fresh soil samples approximately.

16. Next day, first weigh the crucibles with dry soil samples and then the empty crucibles.

Precautions

1. Adequate period is allowed for mixing the water with soil before compaction.

2. The blows should be uniformly distributed over the surface of each layer.

3. Each layer of compacted soil is scored with a spatula before placing the soil for the succeeding layer.

4. The amount of soil used should be just sufficient to fill the mould i.e. at the end of compacting the last layer the surface of the soil should be slightly (5 mm) above the top rim of the mould.

5. Mould should be placed on a solid foundation during compaction.

Observations and Calculations

1. Enter all observations in table 1 and calculate the wet density.

2. Calculate the dry density by using the equation

$$\gamma_d = \frac{\gamma_t}{1+w} \qquad (8\text{-}1)$$

Where γ_d = dry density (g/cc)

γ_t = wet density (g/cc)

w = water content

3. Plot the water content on x-axis and dry density on y-axis draw the smooth curve, called the compaction curve.

4. Calculate the dry density at 100% saturation.

$$\gamma_d = \frac{G_s \gamma_w}{1+\frac{wG_s}{S}} \qquad (8\text{-}2)$$

G_s = specific gravity of soil grains

w = water content

γ_w = unit mass of water (1 g/cc)

S = degree of saturation (one for fully saturated soils).

5. Plot the 100% saturation or Zero Air Voids curve on the same graph.

6. Read the point of maximum density and water content corresponding to maximum density from compaction curve.

7. Calculate the degree of saturation at optimum moisture content using equation 8-2.

QUESTIONS

1. What is compaction of soils? Why is it done?

2. Differentiate between compaction and consolidation of soils.

3. What is optimum moisture content?

4. What is maximum dry density of soil at its O.M.C.? Does it mean that density can not be more than this for a given soil?

5. What is meant by dry side and wet side of optimum? Which side is preferred for field compaction? Explain.

6. What are methods of laboratory compaction of soils.

7. What are the factors affecting the laboratory compaction?

8. What are the field methods of compacting the soils ?

9. What are the factors affecting the compaction in the field ?

10. Which laboratory method did you use ? Explain ?

11. What do you understand by field compaction control ?

12. How does laboratory compaction result help in the control of field compaction ?

13. What are the soil properties affected by compaction ?

14. Are the optimum moisture content and dry density constant for one type of soil ?

15. What is zero air void line ? Why is it plotted with compaction curve ?

16. What are field applications of compaction test ?

17. Why is it called Proctor's compaction test ?

18. Differentiate between Proctor compaction and modified Proctor compaction test ?

19. What is size of mould being used by you ?

20. What is energy imparted by Proctor compaction test and modified compaction test ?

21. What is Jodhpur mini compaction test ? Who has developed it ? What are its advantages ?

22. What is the effect of size and shape of mould on optimum moisture content and dry density If energy per unit volume is constant ?

23. What are the approximate values of optimum moisture content and dry density for coarse grained and fine grained soils ?

24. What are the precautions to be taken during this test ? Explain.

DISCUSSIONS

EXPERIMENT No. 8

COMPACTION TEST

OBSERVATIONS AND CALCULATIONS

Soil Sample No. **TABLE 1** Date

Soil retained on 20 mm sieve (%) =

Soil retained on 4.75 mm sieve (%) =

Soil passing from 4.75 mm sieve (%) =

Specific gravity of soil grains =

Diameter of mould, d (cm) =

Height of mould, h (cm) =

Volume of mould, V (cm^3) =

Mass of mould, W (gm) =

Type of test =

Wt. of rammer =

No. of layers =

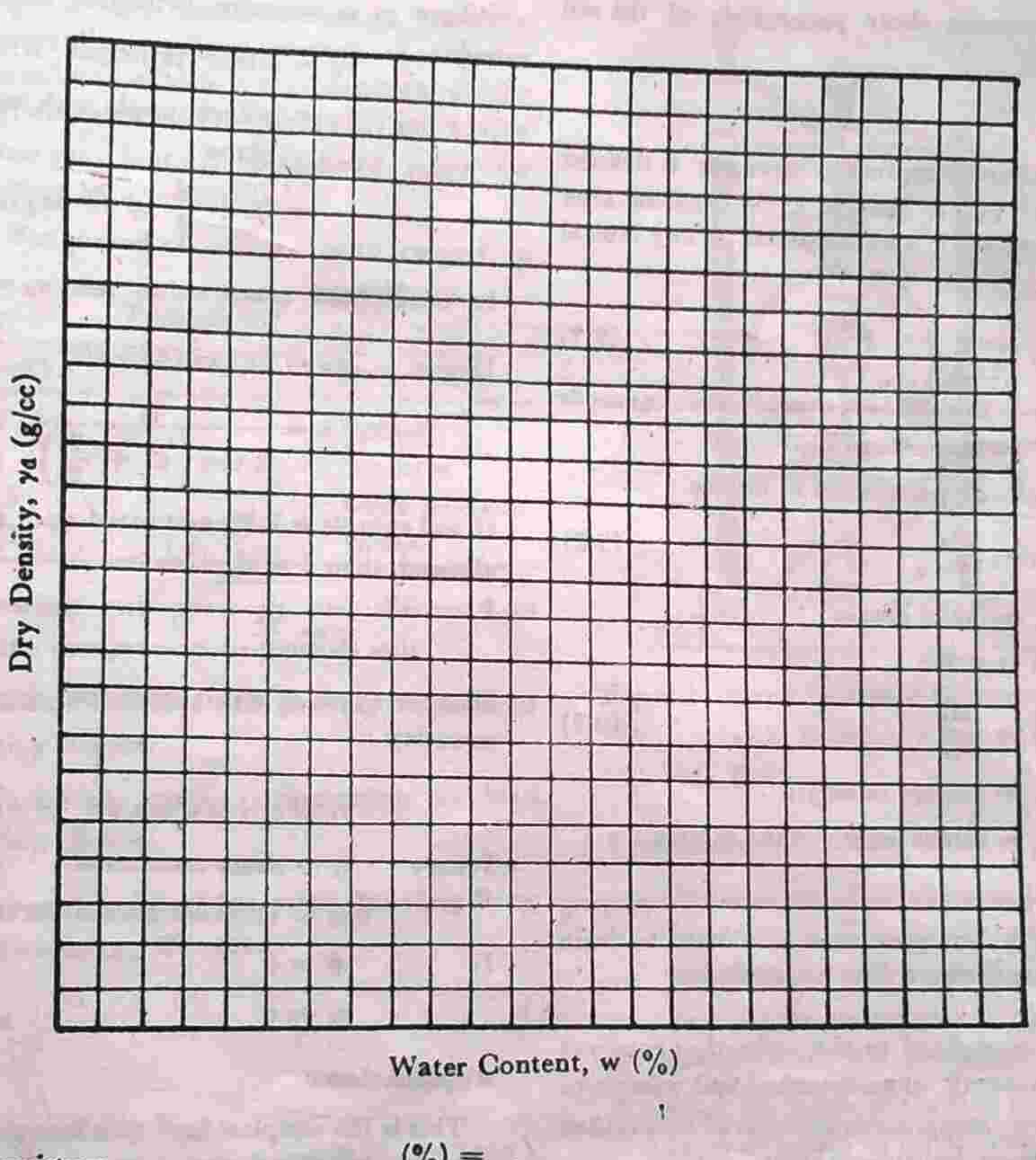
No. of blows/layer =

Determination No.		1	2	3	4	5	6	7
(1) Mass of mould + compacted soil	(gm)							
(2) Mass of compacted soil W_t	(gm)							
(3) Wet density, $\gamma_t = \frac{W_t}{V}$	(g/cc)							
(4) Crucible No.								
(5) Mass of crucible + wet soil,	(gm)							
(6) Mass of crucible + dry, soil,	(gm)							
(7) Mass of water (5) − (6),	(gm)							
(8) Mass of crucible,	(gm)							
(9) Mass of dry soil, (6) − (8)	(gm)							
(10) Water content, w = (7)/(9) × 100	(%)							
(11) Dry density, $\gamma_d = \frac{\gamma_t}{1 + w}$	(g/cc)							
(12) Dry density at 100% saturation	(g/cc)							

EXPERIMENT No. 8

COMPACTION TEST
OBSERVATIONS AND CALCULATIONS

Soil Sample No. **Recommended Graph Sheet** **Date**



Results

Optimum moisture (%) =

Maximum mass dry density, γ_d (g/cc) =

Degree of saturation at O.M.C. (%) =

EXPERIMENT NO. 9

Unconfined Compression Test

Object

(a) To determine the unconfined compressive strength of cohesive soil sample.

(b) To determine sensitivity of the soil sample.

(c) To determine shear parameters of the soil sample.

Theory

The unconfined compressive strength is defined as the ratio of failure load to cross sectional area of the soil sample if it is not subjected to any lateral pressure,

$$q_u = \frac{P}{A_c} \tag{9-1}$$

Where q_u = unconfined compressive strength

P = failure load

A_c = corrected area at failure

Now $$A_c = \frac{A_o}{1 - \xi} \tag{9-2}$$

Where A_o = initial area

ξ = strain

Again $$\xi = \frac{\Delta L}{L_o} \tag{9-3}$$

Where ΔL = change in length

L_o = initial length of the sample

This test is undrained, since the rate of supplying load is so fast that no pore water is allowed to drain and pore water pressure does not dissipate.

Sensitivity is defined as the ratio of unconfined compressive strength of undisturbed soil sample to the unconfined compressive strength of remoulded sample at constant moisture content.

$$\text{Sensitivity} = \frac{(q_u)\ \text{undisturbed}}{(q_u)\ \text{remoulded}}$$

Cohesion of the soil sample may be calculated by using the following relations :

$$\sigma_1 = \sigma_3 \tan^2 \alpha + 2c \tan \alpha \tag{9-4}$$

Where σ_1 = major principal stress at failure

σ_3 = minor principal stress at failure

α = failure angle with major principal plane

$= 45 + \frac{\phi}{2}$ (ϕ = angle of internal friction)

In unconfined compression test $\sigma_3 = 0$, $\sigma_1 = q_u$

Hence $$q_u = 2c \tan (45 + \phi/2) \tag{9-5}$$

$$\therefore \quad c = \frac{q_u}{2 \tan\left(45 + \frac{\phi}{2}\right)} \tag{9-6}$$

If soil sample is fully saturated and no drainage is allowed, then $\phi = 0$, therefore

$$c = \frac{q_u}{2} \tag{9-7}$$

Shear strength of soil is estimated from Coulomb's equation :

$$\tau_f = c + \sigma_{eff} \tan \phi \tag{9-8}$$

Where τ_f = shear resistance

σ_{eff} = effective normal stress

If $\phi = 0$

$$\tau_f = c \tag{9-9}$$

Applications

This is the simplest and quickest test for determining cohesion and shear strength of the cohesive

soils. These values are used for checking the short term stability of foundations and slopes, where rate of loading is fast but drainage is very slow. Soil consistency can easily be known from the value of unconfined compressive strength from the following table :

TABLE 9.1

q_u, KN/cm² (kg/cm²)		Soil consistency
2.5	(< 0.25)	Very soft
2.5 to 5.0	(0.25 to 0.5)	Soft
5.0 to 10.0	(0.5 to 1.0)	Medium
10.0 to 20.0	(1.0 to 2.0)	Stiff
20.0 to 40.0	(2.0 to 4.0)	Very stiff
> 40.0	(> 4)	Hard

Sensitivity is a very useful factor to know the effect of remoulding on shear strength of cohesive soils. Remoulding of soils is very common during pile driving, and excavation. Generally soil having sensitivity less than four are considered good for the construction purposes.

Soils are designated as follows with respect to sensitivity.

TABLE 9.2

Sensitivity	Designation
1—4	Normal
4—8	Sensitive
8—15	Extra sensitive
> 15	Quick

The following two methods are discussed to determine the compressive stregnth of soils.

1. Compression machine with proving ring as load measuring device.
2. Screw jack with spring compression as load measuring device.

A Compression Machine with Proving Ring as Load Measuring Device.

Apparatus

Special :

1. Compression machine
2. Proving ring of capacity 500 N and 1000 N with least count 1.0 and 0.2 N respectively.
3. Dial gauge of least count .01 m.m.
4. Split mould of internal dia 38 m.m. and length 76 m.m.
5. Sampling tube of internal dia 38 m.m. and length 200 m.m.
6. Sample extractor.

General :

1. Stop watch
2. Vernier calliper and scale
3. Knife
4. Balance of accuracy 0.1 gm
5. Grease or oil.

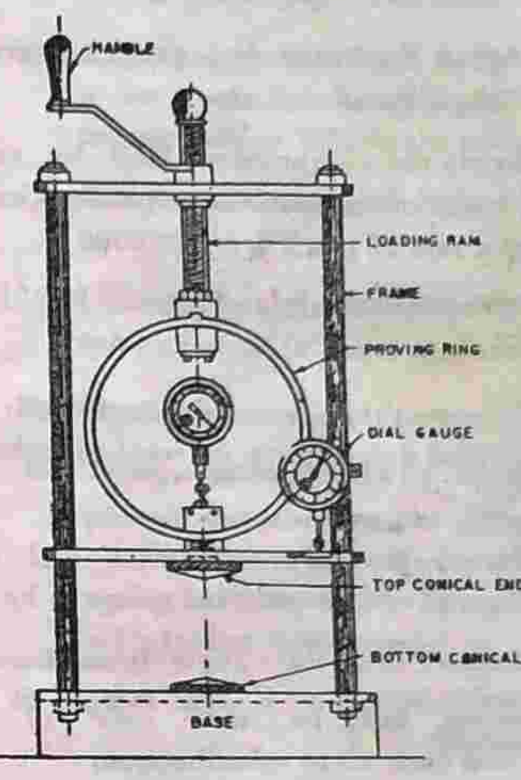


Fig. 9.1 Hand Operated Compression Apparatus with Proving Ring as Load Measuring Device.

Procedure

1. Undisturbed—Push the sampling tube into the clay samples. Remove the sampling tube along with the soil.
2. Saturate the soil sample in sampling tube by a suitable method if possible.
3. Coat the inside of the split mould with a thin layer of grease or oil to prevent adhesion of the soil.

4. Extrude the specimen from the sampling tube to the split mould with the help of sample extractor and knife.

5. Trim the two ends of the mould sample.

6. Weigh the soil sample and the mould.

7. Remove the sample from the mould by spliting it in two parts.

8. Measure the length and diameter of the specimen.

9. Place the specimen on the bottom plate of the compression machine.

10. Raise the bottom plate of the machine to make contact of the specimen with the upper plate.

11. Adjust the strain dial gauge and proving ring dial gauge to read zero.

12. Apply the compression load by raising the bottom of the machine to produce axial strain at a rate of $\frac{1}{2}$ to 2% per minute.

13. Record the strain and proving ring dial gauges readings every 30 seconds.

14. Compress the specimen till it fails or 20% vertical deformation is reached whichever is earlier.

15. Note the least count of strain dial gauge in m.m./divn. and load dial gauge in kg./divn.

16. Measure the failure angle from horizontal if *possible* specially if soil sample *is not fully saturated.*

17. Determine the moisture content of the specimen.

Precautions

1. The specimen should be handled carefully to prevent disturbances, change in density or loss of moisture. Loss of moisture during the testing may be checked by sealing the specimen with rubber membranes.

2. Two ends of the specimen should be perpendicular to the long axis of the specimen.

3. The seating of the sample should be proper on the upper and lower plates.

4. The loading of the sample should be at constant rate.

5. Remoulded specimen should be prepared at the same moisture content and density as of undisturbed samnle.

6. If degree of saturation is less than 100%, dont forget to measure the failure angle.

7. The sample should always be pushed in the sampling tube or the mould along the same direction in which it enters the tube in the field.

8. Do not interchange the least count and observations of deformation dial gauge with proving ring dial gauge.

Observations and Calculations

1. Calculate the strain and stress as shown in observation table.

2. Plot the stress-strain curve on graph sheet taking strain on x-axis and stress on y-axis.

3. The maximum value of stress from this plot gives the value of the unconfined strength. Where no maximum is observed, stress at 20% strain will give the unconfined compressive strength.

4. Calculate the sensitivity of the specimen

$$\text{Sensitivity} = \frac{(q_u)\ \text{undisturbed}}{(q_u)\ \text{remoulded}}$$

5. If failure angle (α) has been measured, calculate the angle of internal friction $\phi_u = (\alpha - 45) \times 2$.

6. Calculate the value of cohesion c_u.

$$c_u = \frac{q_u}{2} \text{ if sample is fully saturated.}$$

$$c_u = \frac{q_u}{2 \tan \alpha} \text{ if sample is partially saturated}$$

7. Read soil consistency and designation from table 9.1 and 9.2.

Screw Jack with Spring Compression at Load Measuring Device

Apparatus

Special

1. Unconfined compression apparatus (screw jack with spring load measuring device).

2. Sampling tube of initial diameter 38 mm and length 200 mm.
3. Sample extractor.
4. Split mould of internal diameter 38 mm and length 76 mm
5. Coning tool

General

1. Stop watch
2. Scale and knife
3. Vernier callipar
4. Balance of accuracy 0.1 gm.
5. Grease or oil
6. Drying crucibles
7. Drying oven
8. Desiccator

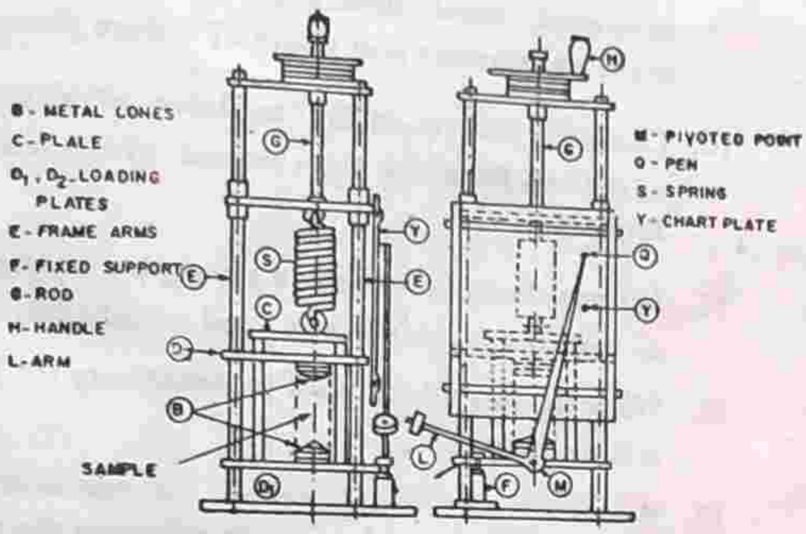


Fig. 9 2 Unconfined Compression Apparatus with Spring as Load Measuring Device.

Procedure

1. Undisturbed—Push the sampling tube into clay sample. Remove the sampling tube along with the soil.
2. Saturate the soil sample in the sampling tube by a suitable method if possible.
3. Coat the inside of the spilt mould with a thin layer of grease or oil to prevent the adhesion of the soil.
4. Excrude the specimen from the sampling tube to the split mould with the help of sample extractor and knife.
5. Trim the two ends of the mould specimen carefully.
6. Determine the weight of the soil specimen inside the mould by weighing the mould with specimen and empty.
7. Use the coning tool to form cones on two ends of the specimen.
8. Remove the specimen from the mould by spliting it in two parts.
9. Measure the length and diameter of the specimen.
10. Place the specimen in the compression apparatus.
11. Fix the graph paper and pencil.
12. Apply compressive load by giving about half a turn of the handle per second till the sample fails or 20% strain occurs.
13. Measure the angle of failure plane from the horizontal.
14. Determine the moisture content of the soil sample.

Precautions

1. The specimen should be handled carefully to prevent disturbances, change in density or loss of moisture. Loss of moisture during the testing may be checked by sealing the specimen with rubber membranes.
2. Two ends of the specimen should be perpendicular to the long axis of the specimen.
3. The sealing of the sample should be proper on the upper and lower conical ends.
4. Specimen and mould should be weighed before using the coning tool.
5. The pencil should be fixed carefully so as to press the paper and draw a smooth curve.
6. The horizontal arm of the lever must rest on the adjustable stop while the load is applied.
7. The loading of the sample should be at constant rate.

8. Remoulded specimen should be prepared at the same moisture content and density as of undisturbed sample.

9. If degree of saturation is less than 100%, do not forget to measure the failure angle.

10. The sample should always be pushed in the sampling tube or the mould along the same direction in which it enters the main tube in the field.

Observations and Calculations

1. Note the point of maximum spring extension on the graph paper if sample has failed. Select any three points on the right hand side and one point on the left hand side of the point of maximum extension.

2. Read the spring extensions and deformations corresponding to these points.

3. Calculate the compressive stresses for these points. Maximum stress will give the unconfined compressive strength.

4. If sample does not fail, stress corresponding to 20% strain is taken as unconfined compressive strength.

5. Calculate the sensitivity of the soil

$$= \frac{(q_u) \text{ undisturbed}}{(q_u) \text{ remoulded}}$$

6. Calculate the angle of internal friction ϕ_u if failure angle α has been measured for partially saturated samples.

$$\phi_u = (\alpha - 45) \times 2$$

7. Calculate the value of cohession c_u

$$c_u = \frac{q_u}{2} \text{ if sample is fully saturated}$$

$$c_u = \frac{q_u}{2 \tan \alpha} \text{ if sample is partially saturated.}$$

QUESTIONS

1. What do you understand by unconfined compressive strength of soil ?
2. Can you determine the unconfined compressive strength for all type of soils ? Explain.
3. What is corrected area ? How is it obtained ?
4. What are the drainage condition in unconfined compression test ?
5. What is the difference between unconfined compression test and unconsolidated undrained triaxial test ?
6. What are shear parameters ? How do you get these by unconfined compression test ?
7. What is Coulomb's shear strength equation ?
8. Draw Mohr's stress circle and strength envelope for unconfined compression test.
9. If there are two samples from tde same cohesive soil, one is wet and other is fully saturated, what difference do you expect in shear parameters and angle of failure plane ?
10. Can you determine the modulus of elasticity of the soil from the observations of this test ? Explain.
11. Is unconfined compressive strength a constant ? or variable factor for one kind of cohesive soil ?
12. What do you understand by sensitivity ? How is it estimated ?
13. What are the usual values of sensitivity of clays ? What are the factors affecting the value of sensitivity of the soils ?
14. How do you estimate the soil consistency from the value of unconfined compressive strength ?
15. What are the practical applications of the unconfined compressive strength and sensitivity of soils ?
16. What do you understand by undisturbed, compacted and remoulded soil samples ? What are the different field problems which will govern the selection of type of soil sample for laboratory testing ?
17. What is the size of your soil sample ? What is the length-diameter ratio ? Explain ?

18. What is the effect of shape, size and length-diameter ratio of samples on unconfined compressive strength ?

19. Is your method a stress control or strain control ?

20. What is the rate of strain, you applied ? How much total time is taken in testing one sample ?

21. How do you measure the loads and deformations in this test ?

22. If failure point is not observed during testing, what is the maximum strain to which testing is done ?

23. Compare the unconfined compression test with triaxial and direct shear box tests ?

DISCUSSIONS

EXPERIMENT No. 9

UNCONFINED COMPRESSION TEST
OBSERVATIONS AND CALCULATIONS

Soil Sample No. **TABLE 1** Date

		Type of sample	
		Undisturbed	Remoulded
(1) Initial length of the specimen, L_o	(mm)		
(2) Initial diameter of the specimen,	(mm)		
(3) Initial area of the specimen,	(cm^2)		
(4) Initial volume of the specimen, V_o	(cm^3)		
(5) Mass of the specimen + mould	(gm)		
(6) Mass of the mould	(gm)		
(7) Mass of the specimen, W = (5) − (6)	(gm)		
(8) Density of the specimen, $\gamma_t = \frac{(7)}{(4)}$	(g/cc)		
(9) Crucible No.			
(10) Mass of crucible + wet soil	(gm)		
(11) Mass of crucible + dry soil	(gm)		
(12) Mass of crucible	(gm)		
(13) Water content, $w = \frac{(10)-(11)}{(11)-(12)} \times 100$	(%)		
(14) Void ratio, $e_o = \frac{G_s(1+w)\gamma_w}{\gamma_t} - 1$			
(15) Degree of saturation, $S = \frac{G_s w}{e_o} \times 100$	(%)		

EXPERIRMENT No. 9

UNCONFINED COMPRESSION TEST

OBSERVATIONS AND CALCULATIONS

Soil Sample No.

TABLE 2 (a)

Date

(For Compression Machine with Proving Ring)

(i) Type of specimen - Undisturbed/Remoulded =

(ii) Least Count of deformation dial gauge (mm/divn.) =

(iii) Proving ring constant (N/divn.) =

S. No.	Elapsed time (min)	Deformation (ΔL)		Strain	Corrected Area	Load		compressive stress, q
		(divn.)	(m.m)	$(\xi) = \frac{\Delta L}{L_o}$	$A_o = \frac{A_o}{1-\xi}$, (cm)^2	(divn.)	(N)	(N/cm^2)
(1)	(2)	(3)	(4)=(3) × L.C.	(5)	(6)	(7)	(8)=(7) × (iii)	(9)=(8)/(6)
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								

Failure Angle (degree) =

Note :—Use as many tables as the number of specimens

EXPERIMENT No. 9

UNCONFINED COMPRESSION TEST

OBSERVATIONS AND CALCULATIONS

TABLES 2 (b)

Soil Sample No. Date

(For Compression Machine with Providing Ring)

(i) Type of specimen - Undisturbed/Remoulded =
(ii) Least Count of deformation dial gauge (mm/divn.) =
(iii) Proving ring constant (N/divn.) =

S. No.	Elapsed time (min)	Deformation (ΔL)		Strain (ξ) = $\frac{\Delta L}{L_o}$	Corrected Area $A_o = \frac{A_o}{1-\xi}$ (cm)^2	Load		compressive stress, q (N/cm^2)
		(divn.)	(m.m)			(divn.)	(N)	
(1)	(2)	(3)	(4)=(3) × L.C.	(5)	(6)	(7)	(8)=(7) × (iii)	(9)=(8)/(6)
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								

Failures Angle (degree) =

Note :—Use as many tables as the number of specimens

EXPERIMENT No. 9

UNCONFINED COMPRESSION TEST
OBSERVATIONS AND CALCULATIONS

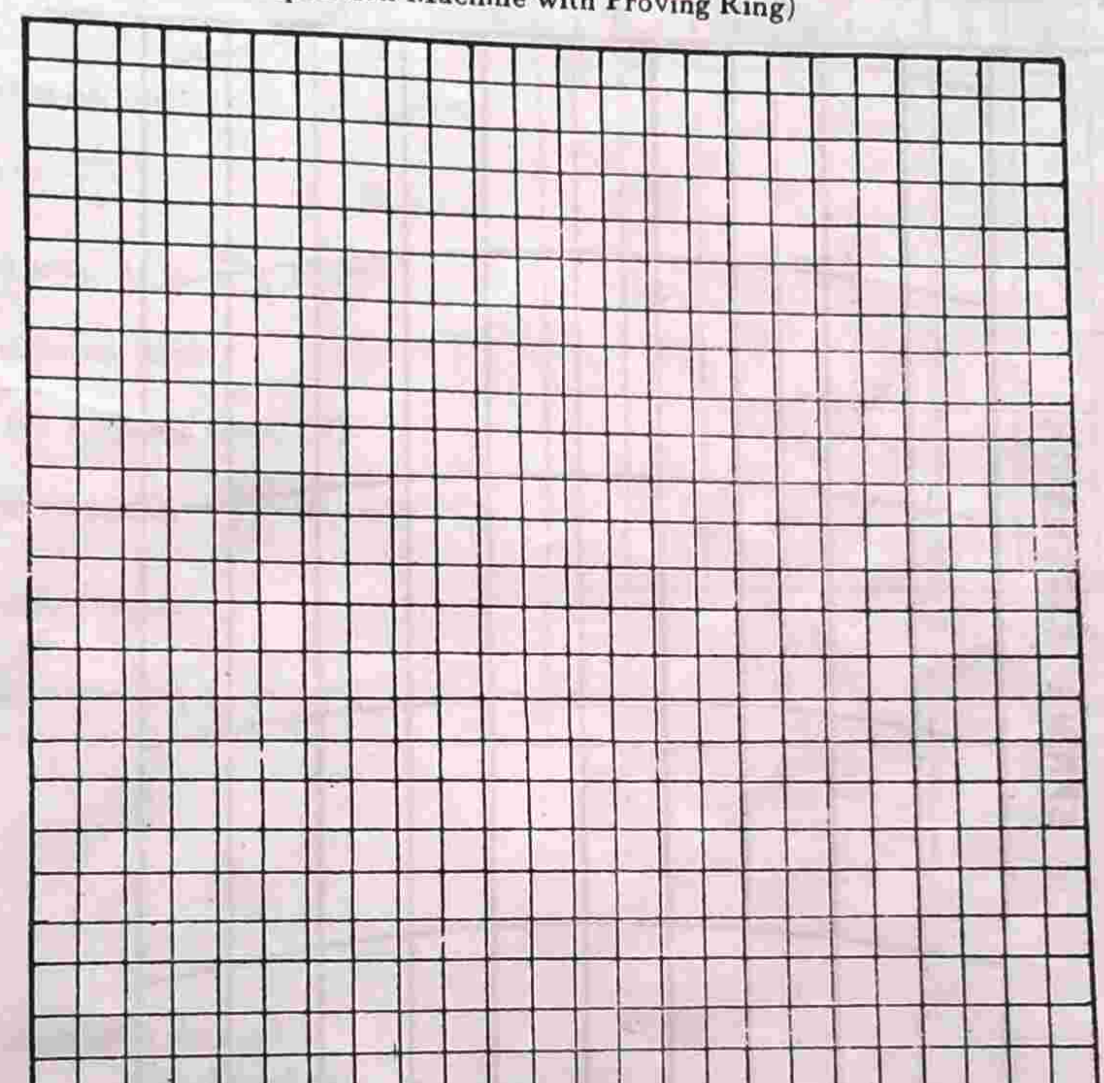
Soil Sample No.

Recommended Graph Sheet 3

Date

(For Compression Machine with Proving Ring)

Axial Stress, q (N/cm^2)



Axial Strain, $\Delta L/L_0$ (%)

Results

Unconfined compressive strength q_u N/cm^2 =

Strain at failure (%) =

Cohesion c_u N/cm^2

Angle of internal friction ϕ_u =

Soil consistency =

Sensitivity and designation =

EXPERIMENT No. 9

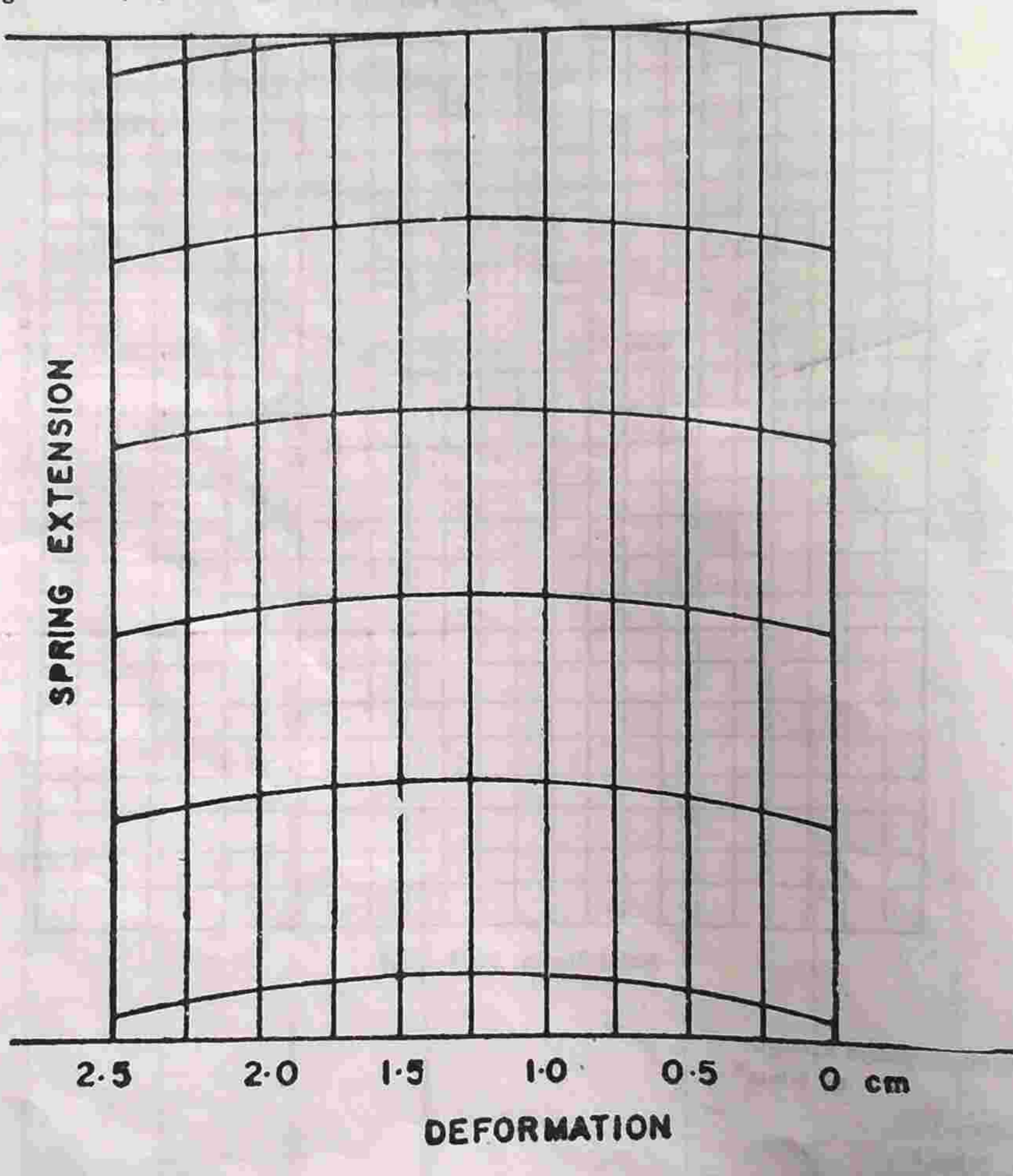
UNCONFINED COMPRESSION TEST
OBSERVATIONS AND CALCULATIONS

Soil sample No. Recommended Graph Sheet 4 Date

(For Screw Jack with Spring compression)

(i) Type of specimen—Undisturbed/Remoulded

(ii) Spring constant, N/cm =



EXPERIMENT No. 9

UNCONFINED COMPRESSION TEST

OBSERVATIONS AND CALCULATIONS

Soil Sample No

Date

TABLE 5

(For Screw Jack with Spring Compression)

Points on the curve	Undisturbed					Remoulded				
	1	2	3	4	5	1	2	3	4	5
(1) Deformation ΔL (cm)										
(2) Strain, $\xi = \frac{\Delta L}{L_o}$										
(3) Corrected area, $A_c = \frac{A_o}{1-\xi}$ (cm^2)										
(4) Spring extension, (cm)										
(5) Load = (4) × spring const, (N)										
(6) Compressive stress, $q = \frac{(5)}{(3)}$, (N/cm^2)										
(7) Failure angle (degree)										
(8) Compressive strength q_u (N/cm^2)										

Results

Unconfined compressive strength

q_u N/cm^2 =

Strain at failure (%) =

Cohesion c_u N/cm^2 =

Angle of internal friction ϕ_u =

Soil consistency =

Sensitivity and designation =

EXPERIMENT No. 10

Direct Shear Test

Object

1. To determine shear strength parameters of the given soil sample at known density and moisture content by direct shear test.

Theory

Shear strength of a soil is its maximum resistance to shearing stress at failure on the failure plane. Shear strength is composed of :

(i) Internal friction which is the resistance due to friction between individual particles at their contact points and interlocking of particles.

(ii) Cohesion which is resistance due to inter-particles forces which tend to hold the particles together in a soil mass. Coulomb has represented the shear strength of soil by the equation :

$$\tau_f = c + \sigma_n \tan \phi \qquad (10\text{-}1)$$

Where τ_f = shear strength of soil
= shear stress at failure.
c = cohesion
σ_n = total normal stress on the failure plane
ϕ = angle of internal (shearing) friction.

The parameters c and ϕ are not constant for type of soil but depends on its degree of saturation and the condition of laboratory testing. There are three types of laboratory test.

(a) Undrained Test—Water is not allowed to drain out during the entire test, hence there is no dissipation of pore pressure.

(b) Consolidated Undrained Test – Soil is allowed to consolidate under the initially applied normal stress only, hence drainage is permitted. But no drainage is allowed during shear.

(c) Drained Test—Drainage is allowed throughout the test during the application of both normal and shear stresses. No pore pressure is set-up at any stage of the test.

Coulomb's shear strength equation has been modified on the concept of pore pressure development. Modified equation is :

$$\tau_f = c' + \sigma' \tan \phi \qquad (10\text{-}2a)$$

or

$$\tau_f = c' + (\sigma - u) \tan \phi \qquad (10\text{-}2b)$$

where c' = effective cohesion
σ' = effective normal stress
u = pore pressure
σ = total normal stress
ϕ = effective angle of shearing resistance

Applications

The purpose of direct shear test is to get the ultimate shear resistance, peak shear resistance cohesion, angle of internal friction, ϕ and *shear stress-strain characteristics of the soils*.

Shear parameters are used in the design of earthen dams and embankments. These are used in calculating the bearing capacity of soil-foundation systems. Parameters help in estimating the earth pressures behind the retaining walls. The values of these parameters are also used in checking the stability of natural slopes, cuts and fills.

Apparatus

Special :

1. Shear box (Non-corrosive metal, size 60 mm × 60 mm × 50 mm).

2. Container for shear box.
3. Grid plates (two plain and two perforated, depth of serrations 1.5 mm).
4. Base plate (non-corrosive metal with cross-grooves on its top face).
5. Prous stones (two, 6 mm thick).
6. Loading pad.
7. Loading frame.
8. Loading yoke.
9. Proving ring with dial gauge (capacity 1.5-2.0N accuracy of dial gauge .002 mm).
10. Other accessaries (two fixing screws, two spacing screws)
11. Static/dynamic compaction device (for remoulded samples).

General

1. Sample trimmer
2. Stop clock
3. Balance (capacity 1 kg, sensitivity 0.1 gm capacity 160 gm sensitivity .01 gm).
4. Spatula and straight edge.
5. Drying crucibles.
6. Drying oven.
7. Scale.
8. Deaired water (for saturated samples).
9. Dial gauges (two, sensitivity .01 mm).
10. Weights,
11. Oven.

Procedure

1. Prepare a soil specimen of size 6 cm × 6cm × 2 cm either from undisturbed soil sample or from compacted and remoulded sample[a]. Soil specimen may directly be prepared in the box by compaction.
2. Fix the upper part of the box to the lower part by the fixing screws. Attach the base plate to the lower part.
3. Place a porous stone in the box.
4. For undrained test, place the grid on the stone, keeping the serrations of the grid at right angle to the direction of shear. For consolidated undrained and drained tests, use the perforated grid in place of plain grid.
5. Weigh the box with base plate, porous stone and grid
6. Transfer the soil specimen prepared in step in the box.
7. Weigh the box with soil specimen.
8. Place the upper grid, porous stone and loading pad in the order on soil specimen.
9. Place the box inside the container and mount it on loading frame.

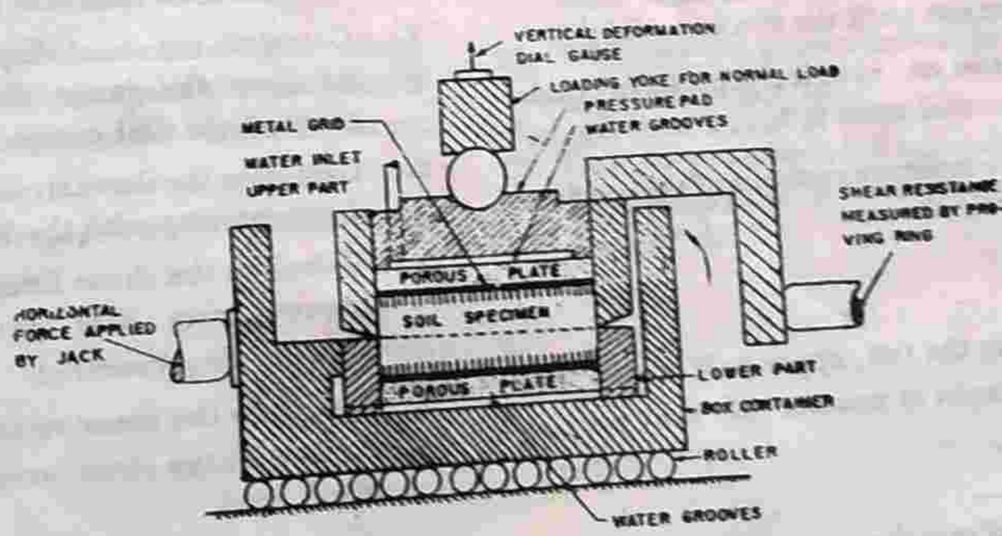


Fig. 10.I Shear Box Test

(a) Compaction may be done statically or dynamically. It is experienced that static compaction is more convenient to compact the cohesive soil at any desired density and moisture content.

10. Bring the upper half of the box in contact with proving ring assembly. Contact is observed by a slight movement of proving ring dial gauge.
11. Fill the container with water if soil is to be saturated.
12. Mount the loading yoke on the ball placed on the loading pad.
13. Mount one dial gauge on the yoke to record the vertical movement and other dial gauge on the container to record the shear movement.
14. Put the weights on the loading yoke to apply the normal stress of intensity 2.5 N/cm^2. *Add the weight of yoke also in* estimating the normal stress intensity.
15. For consolidated undrained and drained tests allow the soil to consolidate fully under this normal load. This step is avoided for undrained test.
16. Remove the fixing screws from the box and raise slightly the upper half box with the help of spacing screws. Remove the spacing screws also.
17. Adjust all the three dial gauges to read zero.
18. Shear load is applied at a constant rate of strain[b].
19. Record readings of proving ring dial gauge and vertical and shear movement dial gauges at every half minute.
20. Continue the test until the specimen fails[c].
21. Repeat the test on identical specimen under increasing normal stress 0, 5, 1, 2 and $4 kg/cm^2$.
22. Determine the moisture contents of the specimen before and after the test.

Precautions

1. Before starting the test, upper half of the box should be brought in contact of the proving ring assembly.
2. Before subjecting the specimen to shear, the fixing screws should be taken out.
3. Spacing screws should also be removed before shearing the specimen.
4. The vertical stress on the sample should remain uniform, vertical and constant during the test.
5. The rate of strain should be constant throughout the test.
6. The shearing strain and stress should be applied in the same plane as the dividing plans of the two parts of the box.
7. No vibrations should be transmitted to the specimen during the test.
8. For drained tests, the porous stones should be deaired and saturated boiling.
9. Do not forget to add the self weight of loading yoke in the vertical loads.
10. Do not mix with each other the least counts and readings of the three dial gauges.

Observations and Calculations

1. Calculate the normal stress by dividing the total normnl load with the area of the shear box.

Normal stress,

$$\sigma = \frac{\text{weight of yoke} + \text{normal load}}{\text{area of the shear box}}$$

2. Calculate the normal displacements by multiplying the normal dial gauge divisions with the least count of that dial gauge.
3. Calculate the shear displacements by multiplying shear dial gauge divisions with the least count of the dial gauge.
4. Calculate the shear strains by dividing the shear displacements with the length of the specimen.
5. Calculate the shear force by multiplying the proving ring dial gauge divisions with the proving ring constant.
6. Calculate the shear stress by dividing the shear force with the shear area (equal to area of shear box).

(b) For undrained test the rate of strain is 1 to 1.5 mm per minute in clays and 1.5 mm to 2.5 mm per minute in sand. For drained test, the rate of strain is 0 005 to 0.02 mm per minute in clays and 0.2 to 1 mm per minute in sands.

(c) The failure is assumed when proving ring dial gauge begins to recede after reaching maximum or at a shear displacement of approximately 20% of the specimen length.

7. Use sheet 3 (graph paper) to draw the shear stress-strain curves, take shear strain on x-axis and shear stress on y-axis, corresponding to each normal stress.
8. Read the maximum value of shear stress if failure has occured, otherwise read the shear stress at 20% strain which is *defined as failure shear stress*.
9. Use sheet 4 (graph paper) to plot the normal stress on X-axis and corresponding shear stress at failure on Y-axis. Join the points by smooth curve. This is defined as the shear strength envelope.
10. Read the slope of the line, which is defined as the angle of shearing resistance and the intercept of the line with Y-axis, the cohesion of the soil.

QUESTIONS

1. What is understood by shear strength of soils ?
2. What is Coulomb's shear strength equation ?
3. What are angle of internal friction and cohession of soil ?
4. What are shear strength parameters ? Are these constant or variable for one type soil ?
5. What are undrained, consolidated undrained and drained tests ? When are they performed ?
6. What are apparent and effective shear strength parameters ? When are they used ?
7. What are Mohr's stress circle and Mohr strength envelope ? Draw them for undrained consolidated undrained and drained direct shear box tests ?
8. What is the role of pore water pressure on shear strength of soils ?
9. Differentiate between angle of repose and angle of shearing resistance of soils.
10. Differentiate between peak and ultimate shear resistance of soils. Which is used for design ? Explain.
11. Explain the physical law governing the failure in shear of a soil.
12. What are the methods to increase the shear strength of soils ?
13. What are the relative merits and demerits of direct shear box test over the unconfined compression and triaxial tests.
14. What are the other laboratory and field methods to determine the shear strength of soils ?
15. What are the applications of *shear strength* parameters in the field problems ?
16. How do you prepare the soil specimen at given dry density and moisture content ?
17. Why do you put the grids keeping the *serrations* at right angle to the direction of shear ?
18. Why do you provide the space between the two parts of the box ? How much is it provided ?
19. Are you using a stress control or strain control device ?
20. What is the rate of strain of your test ? What is the total strain at failure ?
21. What are the precautions to be taken in the direct shear box test ?
22. How do you ensure full saturation and complete dissipation of pore water pressure during the drained test ?

DISCUSSIONS

EXPERIMENT No. 10

DIRECT SHEAR TEST
OBSERVATIONS AND CALCULATIONS

Soil Sample No. TABLE 1 Date

(i) Size of box, (cm) = (iii) Thickness of sample, cm =

(ii) Area of box, (cm^2) = (iv) Volume of sample, (cm^3) =

Test No.		1	2	3	4	5
(before test)						
(1) Mass of box	(gm)					
(2) Mass of box + soil,	(gm)					
(3) Mass of soil used, (2) − (1)	(gm)					
(4) Density of Soil, $\gamma = \frac{(3)}{(iv)}$	(g/cc)					
(5) Mass of drying crucible with no.	(gm)					
(6) Mass of crucible + wet soil,	(gm)					
(7) Mass of crucible + dry soil,	(gm)					
(8) Mass of water, w_w = (6)−(7),	(gm)					
(9) Mass of dry soil, W_s = (7) — (5)	(gm)					
(10) Water content, w_1 = (8) / (9)						
(11) Dry density, $\gamma_d = \frac{\gamma}{1 + w_1}$	(g/cc)					
(After test)						
(12) Mass of crucible with No.	(gm)					
(13) Mass of crucible + wet soil,	(gm)					
(14) Mass of crucible + dry soil,	(gm)					
(15) Water content, w_2 − (13)−(14)/14)−(12)						
(During test)						
(16) Mass of yoke + normal weight	(N)					
(17) Normal stress, σ,	(N/cm^2)					
(18) Shear force at failure,	(N)					
(19) Shear stress at failure, τ_f	(N/cm^2)					

EXPERIMENT No. 10

DIRECT SHEAR TEST

OBSERVATIONS AND CALCULATIONS

Soil Sample No.

TABLE 2 (a)

Date

Least count of normal dial gauge, (mm/div.) =

Least count of shear dial gauge, (mm/piv.) =

Proving ring constant, (N/div.) =

Normal weight + weight of yoke, (N) =

Area of box (cm^2) =

Normal stress applied, σ (N/cm^2) =

Elapsed time	Shear displacement		Shear strain	Normal displacement		Shear Force		Shear Stress τ
	(Div.)	(mm)		(Dlv.)	(mm)	(Div.)	(N)	(N/cm^2)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)

Note :—Use as many tables as the number of normal stresses

EXPERIMENT No. 10

DIRECT SHEAR TEST

OBSERVATIONS AND CALCULATIONS

Soil Sample No.

TABLE 2 (b)

Date

Least count of normal dial gauge, (mm/div.) =

Least count of shear dial gauge, (mm/div.) =

Proving ring constant, (N/div.) =

Normal weight+weight of yoke, (N) =

Area of box (cm^2) =

Normal stress applied, σ (N/cm^2) =

Elapsed time	Shear displacement		Shear strain	Normal displacement		Shear Force		Shear Stress τ (N/cm^2)
	(Div.)	(mm)		(Div.)	(mm)	(Div.)	(N)	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)

EXPERIMENT No. 10

DIRECT SHEAR TEST

OBSERVATIONS AND CALCULATIONS

Soil Sample No.

TABLE 2 (c)

Date

Least count of normal dial gauge, (mm/div.) =
Least count of shear dial gauge, (mm/piv.) =
Proving ring constant, (N/div.) =
Normal weight+weight of yoke, (N) =
Area of box (cm^2) =
Normal stress applied, σ (N/cm^2) =

Elapsed time	Shear displacement		Shear strain	Normal displacement		Shear Force		Shear Stress
	(Div.)	(mm)		(Dlv.)	(mm)	(Div.)	(N)	τ (N/cm^2)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)

EXPERIMENT No. 10

DIRECT SHEAR TEST

OBSERVATIONS AND CALCULATIONS

Soil Sample No.

TABLE 2 (b)

Date

Least count of normal dial gauge, (mm/div.) =

Least count of shear dial gauge, (mm/div.) =

Proving ring constant, (N/div.) =

Normal weight+weight of yoke, (N) =

Area of box (cm^2) =

Normal stress applied, σ (N/cm^2) =

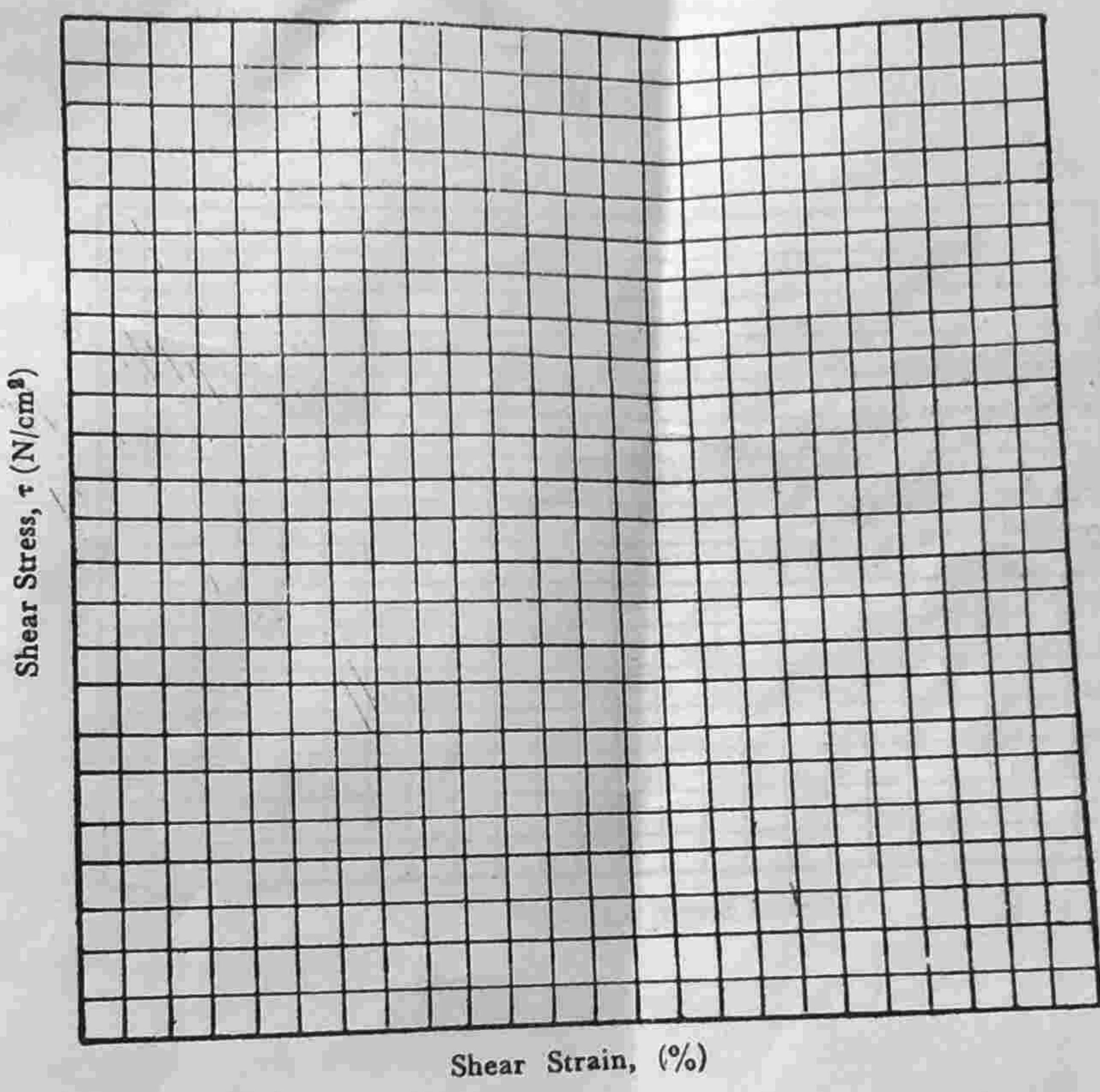
Elapsed time	Shear displacement		Shear strain	Normal displacement		Shear Force		Shear Stress τ (N/cm^2)
	(Div.)	(mm)		(Div.)	(mm)	(Div.)	(N)	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)

EXPERIMENT No. 10

DIRECT SHEAR TEST

OBSERVATIONS AND CALCULATIONS

Soil Sample No. Recommended Graph Sheet 3 Date

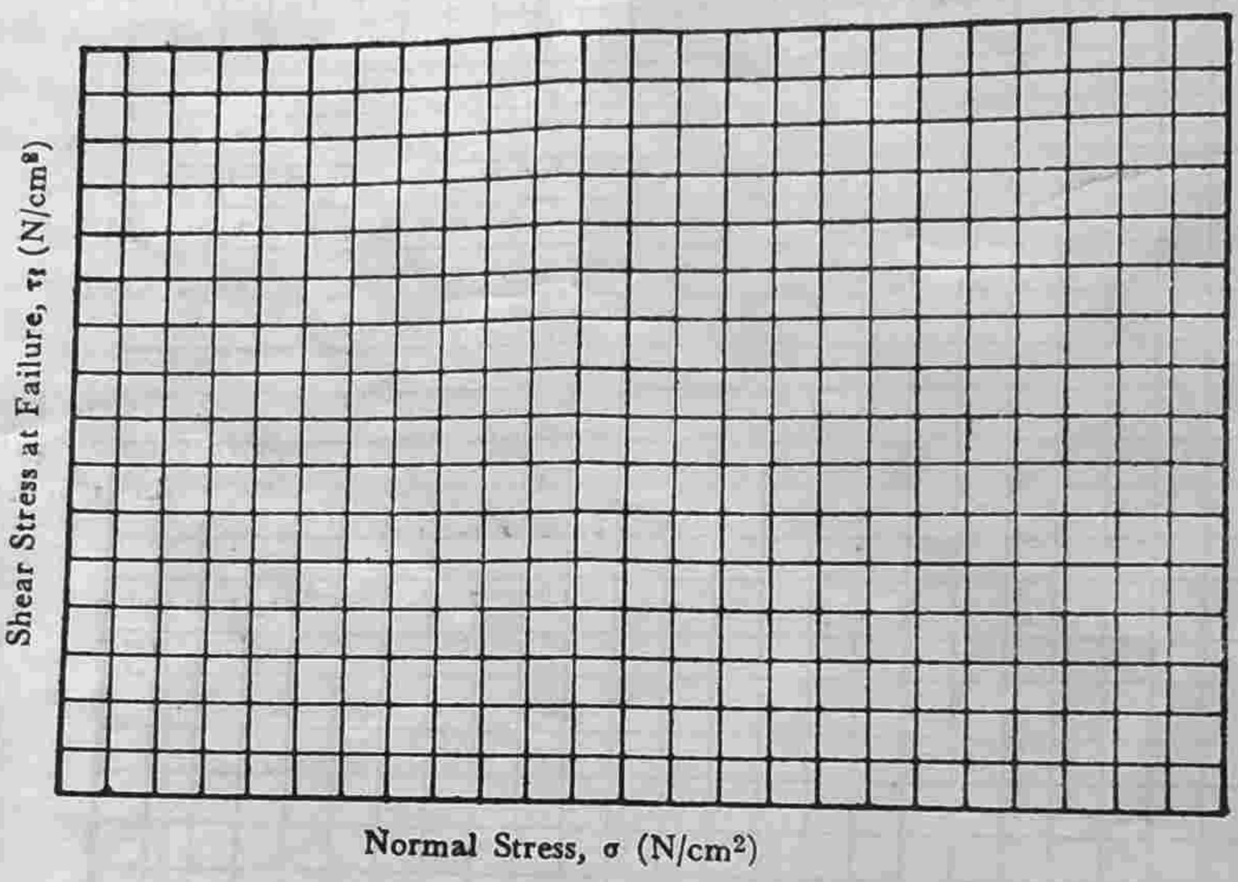


EXPERIMENT No. 10

DIRECT SHEAR TEST

OBSERVATION AND CALCULATION

Soil Sample No. Recommended Graph Sheet 4 Date



Results

(i) **Angle of internal friction, ϕ (degree) =**

(ii) **Cohesion, c (N/cm^2) =**

EXPERIMENT No. 11

In-Place Density Test

Object

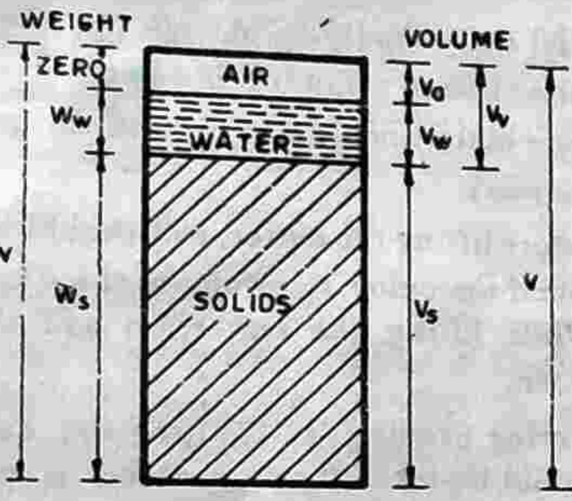
1. To determine the mass density of soils by :
   (a) Core cutter method
   (b) Sand replacement method
2. To estimate void ratio and degree of saturation.

Theory

Density is defined as the mass per unit volume of soil. In Fig. 11.1,

density, $\gamma = \frac{W}{V}$

Where γ = mass density of soil
W = total mass of soil
V = total volume of soil



(The word weight may be replaced by mass)

Fig. 11.1

Here mass and volume of soil comprises the whole soil mass. In the above figure, voids may be filled with both water and air or only air or only water, consequently the soil may be wet or dry or saturated. In soils the mass of air is considered negligible and therefore the saturated density is maximum, dry density is minimum and wet density is in between the two. If soils are found below water table, submerged density is also estimated.

The density can be expressed in g/cm^3, or t/m^3, or kg/m^3, or lb/ft^3. For calculating the submerged density, the density of water is taken as 1 g/cm^3 = 1 t/m^3

Dry density of the soil is calculated by using equation (11-2)

$$\gamma_d = \frac{\gamma_t}{1 + w} \quad (11\text{-}2)$$

Where γ_d = dry density of soil
γ_t = wet density of soil
w = moisture content of soil

Density of soils may be determined by core cutter test, sand replacement test, rubber balloon test, water displacement method and gamma ray method. Void ratio (e) is the ratio of volume of voids to volume of soil solids.

Degree of saturation (S) is defined as the ratio of volume of water to the volume of voids. In Figure 11.1,

$$e = \frac{V_v}{V_s} \times 100 \quad (11\text{-}3)$$

and

$$S = \frac{V_w}{V_v} \times 100 \quad (11\text{-}4)$$

Where e = voids ratio in %
S = degree of saturation in %
V_v = volume of voids
V_s = volume of solids
V_w = volume of water

Further, the following relationships can be obtained from figure 11.1.

$$e = \frac{G_s \gamma_w}{\gamma_d} - 1 \tag{11.5}$$

$$S = \frac{G_s w}{e} \tag{11.6}$$

Where

G_s = specific gravity of soil solids

γ_d = dry density

γ_w = density of water

w = water content

Applications

Density is used in calculating the stress in the soil due to its overburden pressure. It is needed in estimating the bearing capacity of soil foundation system, settlement of footings, earth pressures behind the retaining walls, dams, embankments. Stability of natural slopes, dam, embankments and cutsis checked with the help of density of those soils It is the density which controls the field compaction of soils. Permeability of soils depends upon its density. Relative density of cohesionless soils is determined by knowing the dry density of that soil in natural, loosest and densest states. Void ratio, porosity and degree of saturation need the help of density of soils.

In this chapter the following two methods are discussed to determine the field density of soils.

A. Core cutter method
B. Sand replacement method

A. Core Cutter Method

Apparatus

Special :

1. Cylindrical core cutter (height = 12.74 cm, dia 10 cm)
2. Steel rammer
3. Steel dolley (2.5 cm high and 10 cm internal diameter).

General :

1. Balance (accuracy 1 gm)
2. Balance (accuracy .01 gm)
3. Steel rule
4. Spade or pickaxe
5. Straight edge
6. Knife
7. Water content crucibles
8. Desiccator
9. Oven
10. Tongs

Procedure

1. Measure the height and internal diameter of the core cutter.
2. Weigh the clean core cutter.
3. Clean and level the place where density is to be determined.
4. Press the cylindrical cutter into the soil to its full depth with the help of steel rammer.
5. Remove the soil round the cutter by the spade.
6. Lift up the cutter
7. Trim the top and bottom surfaces of the sample carefully.
8. Clean the outside surface of the cutter.
9. Weigh the core cutter with soil.
10. Remove the soil core from the cutter and take representative sample in the crucibles to determine the moisture content.

Precautions

1. Steel dolly should be placed on the top of the cutter before ramming it down.
2. Core cutter should not be used in gravels and boulders.
3. Before lifting the cutter, soil should be removed round the cutter to minimise the disturbances.
4. While lifting the cutter, no soil should drop down.
5. During pressing and lifting the cutter, care should be taken that some soil is projected at both the ends of the cutter.
6. Values should be reported to second place of decimal.

Observations and Calculations

1. Enter all observations in table 1,
2. Calculate wet dnsity of soil.

$$\gamma_t = \frac{W_2 - W_1}{V}$$

Where

W_2 = mass of cutter + soil

W_1 = mass of cutter only

V = volume of cutter

3. Calculate dry density, void raio and degree of saturation using equations 11.2, 11.5 and 11 6 respectively.

B. Sand Replacement Methoa

Apparatus

Special

1. Sand pouring cylinder
2. Trowel or bent spoon
3. Cylindrical calibrating container
4. Metal tray with hole (30 cm square with 10 cm hole in the centre)
5. Sand (clean oven dried, passing 600 micron sieve)

General

1. Balance (accuracy 1 gm)
2. Balance (accuracy .01 gm)
3. Moisture content crucibles
4. Oven
5. Desiccator
6. Tongs
7. Glass plate (about 45 cm square)
8. Metal tray (about 30 cm square)
9. Scraper tool
10. Measuring jar (1000 cc)

Procedurs

Calibration of Apparatus

1. Measure the internal volume of the calibrating container from the volume of the water required to fill the container.
2. Fill the pouring cylinder with sand within about 1.0 cm of the top and weigh it.
3. Place the pouring cylinder concentrically on the top of the calibrating container.
4. Open the shutter to allow the sand to run out and fill the calibrating cylinder.
5. When there is no further movement of sand in the pouring cylinder, close the shutter.
6. Remove the pouring cylinder and weigh it to the nearest gram.
7. Place the pouring cylinder on a plane surface such as the glass plate.
8. Open the shutter and allow the sand to run out. When there is no movement of sand in the cylinder, close the shutter.
9. Weigh the pouring cylinder with remaining sand

Measurement of Soil Density

1. Clean and level the ground where the field density is required.
2. Fill the pouring cylinder with dry sana within about 1.0 cm of the top and weigh it.
3. Place the metal tray with the central hole over the portion of soil to be tested.
4. Excavate the soil approximately 10 cm dia a 15 cm deep with bent spoon. The hole in the tray will guide the diameter of the hole to be made in the soil.
5. Collect the excavated soil in the metal tray weigh it to the nearest gram.
6. Determine moisture content of the excavated soil.
7. Place the pouring cylinder over the hole so that base of the cylinder covers the hole concentrically.
8. Open the shutter and allow the sand to run out into the hole. When there is no movement of sand, the shutter is closed.
9. Remove the cylinder and weigh it.

Precautions

1. If for any reason it is necessary to excavate the holes to depth other than 15 cm, the calibrating cylinder should be replaced by one of the depth which is the same as the hole to be excavated.
2. Case should be taken in excavating the hole to that it is not enlarged by levering the dibber against the side of the hole, as this will result in lower density being recorded.
3. No loose material should be left in the hole.
4. Initial height of sand in the pouring cylinder should be kept same during calibration and density determinations.

5. There should be no vibrations during this test.
6. Since dry density of soils varies from point to point, it is necessary to repeat the test at several points and to average the result.

Observations and Calculations

1. Enter all the readings in table 2, 3 and 4.
2. Bulk density of sand is calculated as shown in table 2. This density is used in determining the volume of the hole made in the soil.
3. Table 4 shows the calculations of wet density, dry density, void ratio and degree of saturation of the soil.
4. Equations 11.2, 11.5 and 11.6 are used to calculate the dry density, void ratio and degree of saturation respectively.

QUESTIONS

1. Draw the phase diagram for a wet soil.
2. Define dry, wet and saturated densities of the soil.
3. What do you understand by submerged density ? Explain.
4. Mention the field conditions under which different types of densities have to be used.
5. Out of these various types of densities, which one of them is maximum and minimum ? Explain.
6. What are the units of density ?
7. What are the main factors affecting the value of density of soil ? Explain.
8. If you know wet density of a soil, how do you calculate its dry, saturated and submerged densities ?
9. Which density is used in determining the relative density of cohesionless soil ? Explain.
10. Differentiate between density, relative density and specific gravity of a soil.
11. What are the field problems where density is used ?
12. Define void ratio and degree of saturation.
13. Besides density what other properties do you need to calculate void ratio and degree of saturation of soils ?
14. What are the methods to determine in-place (or insitu or field) density of soils ?
15. Compare core cutter and sand replacement methods to determine the field density.
16. How do you determine the field density of soils by rubber balloon method ?
17. What is the effect of *inserting* the core cutter in the soils on the density of soils ?
18. What are the precautions to be taken in cutter method ?
19. What are the precautions to be taken in sand replacement method ?
20. Why do you take the same quantity of sand in the pouring cylinder during calibration and density determination ?
21. Why do you prefer to keep the depth of hole equal to the height of calibrating cylinder ?
22. What modification would you like to make to your sand replacement method if it is used in soils having boulders and stones ?
23. What is hand scoop method to determine the in-place density of soils ?

DISCUSSIONS

77

EXPERIMENT No. 11

IN-PLACE DENSITY

OBSERVATIONS AND CALCULATIONS

TABLE 1

(Core Cutter Method)

Soil Sample No. Date

Internal diamer of cutter (cm) =

Height of cutter (cm) =

Cross-sectional area of cutter (cm^2) =

Volume of cutter, V (cm^3) =

Specific gravity of soil, G_s

(measured or given or assumed) =

Determination No.		1	2	3
(1) Mass of core cutter, W_1	(gm)			
(2) Mass of cutter + soil, W_2	(gm)			
(3) Mass of wet soil, $(W_2 - W_1)$	(gm)			
(4 Moisture content crucible No.				
(5) Mass of crucible	(gm)			
(6) Mass of crucible + wet soil	(gm)			
(7) Mass of crucible + dry soil	(gm)			
(8) Mass of water = (6) − (7)	(gm)			
(9) Mass of dry soil = (7) − (5)	(gm)			
(10) Moisture content, $w = \frac{(8)}{(9)} \times 100$				
Results				
(11) Wet density $\gamma_t = \frac{W_2 - W_1}{V}$	(g/cm^3)			
(12) Dry density $\gamma_d = \frac{\gamma_t}{1+w}$	(g/cm^3)			
(13) Void ratio, $e = \frac{G_s \gamma_w}{\gamma}$				
(14) Degree of saturation, $S = \frac{wG_s}{e} \times 100$	(%)			

EXPERIMENT No. 11

IN-PLACE DENSITY

OBSERVATIONS AND CALCULATIONS

TABLE 2

Soil Sample No. Calibration of Apparatus Date

Determination No.		1	2
(1) Volume of calibrating container, V	(ml)		
(2) Mass of pouring cylinder + sand, W_1' (Before pouring in the calibrating cylinder)	(gm)		
(3) Mass of pouring cylinder + sand, W_2' (After pouring in the calibrating cylinder)	(gm)		
(4) Mass of pouring cylinder + sand, W_3' (Afer making the sand cone on a flat surface)	(gm)		
(5) Mass of sand for filling the calibrating cylinder and cone, $W_4' = (W_1' - W_2')$	(gm)		
(6) Mass of sand for making the cone only, $W_5' = (W_2' - W_3')$	(gm)		
(7) Mass of sand in the calibrating cylinder only, $W_6' = (W_4' - W_5')$	(gm)		
(8) Bulk density of sand, $\gamma_b = \dfrac{W_6'}{V}$	(g/cm^3)		

TABLE 3

Soil Sample No. (Sand Replacement Method) Date

Water Content Determination of Excavated Soil

Determination No.		1	2	3
(1) Crucible No.				
(2) Mass of crucible + wet soil, W_1	(gm)			
(3) Mass of crucible + dry soil, W_2	(gm)			
(4) Mass of crucible W_3	(gm)			
(5) Mass of water, $W_w = W_1 - W_2$	(gm)			
(6) Mass of dry soil, $W_d = W_2 - W_3$	(gm)			
(7) Water content, $w = \dfrac{W_w}{W_d} \times 100$	(%)			

EXPERIMENT No. 11

IN-PLACE DENSITY

OBSERVATIONS AND CALCULATIONS

Soil Sample No.

TABLE 4

Specific gravity of soil solids (given or assumed), G_s =

Date

Determination No.		1	2	3
(1) Mass of pouring cylinder + sand, W_1 (Before pouring in the hole)	(gm)			
(2) Mass of pouring cylinder + sand, W_2 (After pouring in the hole)	(gm)			
(3) Mass of pouring cylinder + sand, W_3 (After making sand cone on a flat surface)	(gm)			
(4) Mass of sand used in the hole and cone, $(W_4 = W_1 - W_2)$	(gm)			
(5) Mass of sand in the cone only $(W_5 = W_2 - W_3)$	(gm)			
(6) Mass of sand in the hole only $(W_6 = W_4 - W_5)$	(gm)			
(7) Volume of sand, $V = \frac{W_6}{\gamma_b}$ (from table 2) (equal to volume of hole)	(cc)			
(8) Mass of tray + excavated soil, W_7	(gm)			
(9) Mass of tray only, W_8	(gm)			
(10) Mass of excavated soil $(W = W_7 - W_8)$	(gm)			
Results				
(11) Wet density of soil $\gamma_t = \frac{W}{V} = \frac{(10)}{(7)}$	(g/cm^3)			
(12) Dry density, $\gamma_d = \frac{\gamma_t}{1+w}$	(g/m^3)			
(13) Void ratio, $e = \frac{G_s \gamma_w}{\gamma_d} - 1$				
(14) Degree of saturation $S = \frac{w G_s}{e} \times 100$	(%)			

Note : w is taken from table 3 and is put in decimals

EXPERIMENT No. 12

Triaxial Shear Test

Object

To determine shear strength parameters i.e. angle of shearing resistance and cohesion of a given soil sample.

Theory

The strength parameters, namely the cohesion (c) and angle of shearing resistance (ϕ) are determined both by laboratory and field tests. In the laboratory, unconfined compression test, direct shear test, vane shear test and triaxial compression test are used. In the field, plate load test, large direct shear test, large vane shear test and block shear test may be performed. Selection of a suitable method will depend upon the type of soil and field conditions. Triaxial tests are superior where confining stress is to be applied and the plane of shear failure is not predetermined. Refer experiments on direct shear test and unconfined compression test for details.

For determining c and ϕ, Mohr's circles are drawn, then strength envelope is obtained. Slope of this envelope will represent the angle of shearing resistance and intersection with ordinate (y-axis) will give the cohesion.

Applications

In deep foundations, confining pressures play the significant role in changing the behaviour of soils. Similarly in high rise earth dams, the confining pressures are of very high magnitude. Triaxial test is the only test to simulate these confining pressures For short term stability of foundations, dams and slopes, shear strength parameters for unconsolidated undrained or consolidated undrained conditions are used, while for long term stability shear parameters corresponding to consolidated drained conditions will give more reliable results. All such special conditions can be achieved in triaxial tests.

Apparatus

Special

1. Triaxial test cell with base, perspex cell and head.
2. Compression machine (speed .05 to 7.5 mm/min; capacity 50 kN).
3. Lateral pressure assembly (accuracy 0.5 N/cm^2 with a pressure gauge).
4. Proving rings (for low strength soils: capacity 1 kN sensitivity 2 N; for high strength soils : capacity 10 kN sensitivity 10 N)
5. Rubber membranes
6. Membrane stretches
7. Rubber 'O' rings
8. Split mould 3.81 cm dia and 7.62 cm height.

General

1. Deaired water supply
2. Vacuum pump
3. Porous stones
4. Balances (0.1 gm and 0.01 gm sensitivity)
5. Drying oven
6. Desiccator
7. Dry crucibles
8. Scale and vernier calipers
9. Dial gauge (0.01 mm accuracy)
10. Spoon
11. Stop watch
12. Volume change burette 25 c.c

Procedure

Dry samples

1. Put a non-porous cap on the bottom pedestal and the rubber membrane slid over it and tie it with the bottom pedestal of the base by O-ring.
2. Put the split mould over the base and the rubber membrane taking through it inside and stretch over it at the top.
3. Weigh the soil in a dish to make a sample of required dry density.
4. For loose dry samples, allow the soil to fall freely and rapidly from a tunnel. For dense samples pour the soil in the mould in layers and compact it by tamping without rupturing the membrane. After the required weight of sand has been used, level the top, place the solid cap over it and seal by O-rings.
5. Operate the vacuum pump and carefully remove the split mould without jarring the sample.
6. Assemble the cell and fill it with water to exert a confining pressure (cell or chamber pressure) of the order of 5 N/cm^2.
7. Raise the loading plate-form of the compression machine to bring the ram in contact with the loading cap.
8. Set the dial gauge on proving ring to zero to compensate for the load-due to cell pressure and piston friction.
9. Set the strain dial gauge to zero just as the ram touches the sample cap.
10. Take readings of the proving ring at a interval of 25 divisions (.25 mm) till sample fails or 20 percent strain is achieved.
11. Make a sketch of the failure of the specimen.
12. Repeat the test for higher cell pressures such as 10, 15, 20, 30 and 40 N/cm^2 at the same initial dry density of sand.

Saturated samples

1. Connect the outlet at the base of the cell to a burette for volume change measurements. Run the water from the burette to remove all air in the line by flushing.
2. Put a porous cap on the pedestal.
3. Seal the rubber membrane to the pedestal with sealing rings.
4. Place the split mould in position and take the membrane through it inside and stretch on the top.
5. Fill the membrane with deaired water.
6. Weigh the required amount of sand and drop into the water without entrapping air.
7. After filling the required weight of sand, level the top.
8. Put a solid cap and seal it by O-rings.
9. Lower the burette and apply a slight vacuum.
10. Remove the split mould and measure the dimensions of the sample.
11. Assemble the cell and fill it with water.
12. Note the initial reading of the burette.
13. Apply the cell pressure equal to 5 N/cm^2.
14. Note the reading of the burette.
15. Raise the loading platform of the compression machine to bring the ram in contact of the loading cap.
16. Set the dial gauge on the proving ring to read zero. This will compensate for the load due to cell pressure and piston friction.
17. The strain dial is adjusted to read zero.
18. Start the machine to apply the normal load. Take readings of the proving ring and burette at intervals of 25 divisions (0.25 mm) till sample fails or 20 percent strain is applied.
19. Make a sketch of failed specimen and measure final dimensions.
20. Repeat the test for higher cell pressure at the same initial density of sand.

Precautions

1. It is essential to maintain the same initial density of sand in all the tests using different lateral pressures. Small difference will result in appreciable errors in the maximum failure

stress.

2. During compaction of sand in the mould, if rupture of membrane takes place, the test should be repeated with new membrane.

3. For tests on saturated sand, there should be no air entrapped in the specimen and lead from bottom of the sample to the burette as the easy flow of water will be prevented

4. For tests on saturated sand, the rate of testing is slow so that no excess pore pressure is generated

5. The mould should be removed carefully, it should not give any jar on the sample.

6. Friction due to end caps should be minimum.

7. There should be no leakage through the cell.

8. During entire period of the test, confining pressure should be kept constant.

Observations and Calculations

1. Use table 1 for calculating the axial stress $(\sigma_1-\sigma_3)$ and ratio of normal stress to lateral stress σ_1/σ_3 for the test on dry sand.

2. For the test on dry sand, calculate the corrected area by using the equation :

$$A_c = \frac{A_o}{1-\xi}$$

where A_c = corrected area

A_o = initial area

$\xi = \frac{\Delta L}{L_o}$, strain

3. Use table 2 for calculating the effective axial stress $(\sigma_1'-\sigma_3')$ and ratio of effective normal stress to effective lateral stress σ_1'/σ_3' for the test on saturated sand.

4. For the drained test on saturated sand, calculate the corrected area by using the equation :

$$A_c = \frac{1-\frac{\Delta V}{V_o}}{1-\xi}, \quad A_o = \frac{V_o-\Delta V}{L_o-\Delta L}$$

where V_o = initial volume

ΔV = change in volume at axial strain ξ.

5. Plot the principal stress difference or ratio against the axial strain and record the maximum value for all confining pressures. Use graph sheet No. 1.

6. Draw Mohr's circles, using σ_1 and σ_3 at failure. Draw strength envelope. The slope of this envelope will give the angle of shearing resistance. Intersection of strength envelope with shear stress axis (y-axis) gives the unit cohesion c. Use graph sheet 2,

7. In case of drained test, effective stress envelope is obtained. The value of angle of shearing resistance is noted as ϕ' or ϕ_d and cohesion as c' or c_d.

Results

Angle of shearing resistance, ϕ (°) =

Unit cohesion, c (N/cm²) =

DISCUSSIONS

EXPERIRMENT No. 12

TRIAXIAL SHEAR TEST
OBSERVATIONS AND CALCULATIONS

Soil Sample No.

TABLE 1

(for test on dry sand)

Date

(i) Diameter of the sample, d (cm) =
(ii) Length of the sample L_o (cm) =
(iii) Initial area of sample, A_o (cm^2) =
(iv) Initial vol. of sample, V_o (cm^3) =
(v) Mass of soil taken, Md =
(vi) Dry unit mass, r_d =
(vii) P.R. constant, N/Div. =
(viii) L.C. of dial, mm/Div. =
(ix) Confining/lateral stress, σ_3 (N/cm^2) =

Deformation		Strain	Corrected area	Load		$(\sigma_1 - \sigma_3)$	$\frac{\sigma_1}{\sigma_3}$
(divn).	(mm) ΔL	$(\xi) = \frac{\Delta L}{L_o}$	$A_c = \frac{A_o}{1-\xi}$ (cm)^2	(divn)	(N)	(N/cm^2)	
(1)	(2) = (1) x L.C.	(3)	(4)	(5)	(6) = (5)x(vii)	(7) = (6)/(4)	(8)

Failure Angle (degree) =

Note :-Use as many tables as the number of specimens

EXPERIMENT No. 12

TRIAXIAL SHEAR TEST

OBSERVATIONS AND CALCULATIONS

Soil Sample No. TABLE 2 Date

(For test on saturated sand)

(i) Diameter of the sample, d (cm) =

(ii) Length of the sample, L_o (cm) =

(iii) Initial area of sample, A_o (cm^2) =

(iv) Initial vol. of sample, V_o (cm^3) =

(v) Mass of soil taken, Md =

(vi) Dry unit mass, r_d =

(vii) P.R. constant, N/Div. =

(viii) L.C. of dial, mm/Div =

(ix) Confining/lateral stress, σ_3' (N/cm^2) =

Deformation		Volume change		length	Volume	Area A_c	Load P			Strain
(divn.)	(m.m) ΔL	Burette reading	ΔV (c.c.)	$(L-\Delta L)$	$(V-\Delta V)$	$= \frac{V-\Delta V}{L-\Delta L}$	(div)	(N)	$(\sigma_1'-\sigma_3') = P/A_c$	$\Delta L/L$
1	2	3	4	5	6	7	8	9	10	11

Note :—Use as many tables as the number of specimens.

EXPERIMENT No. 12

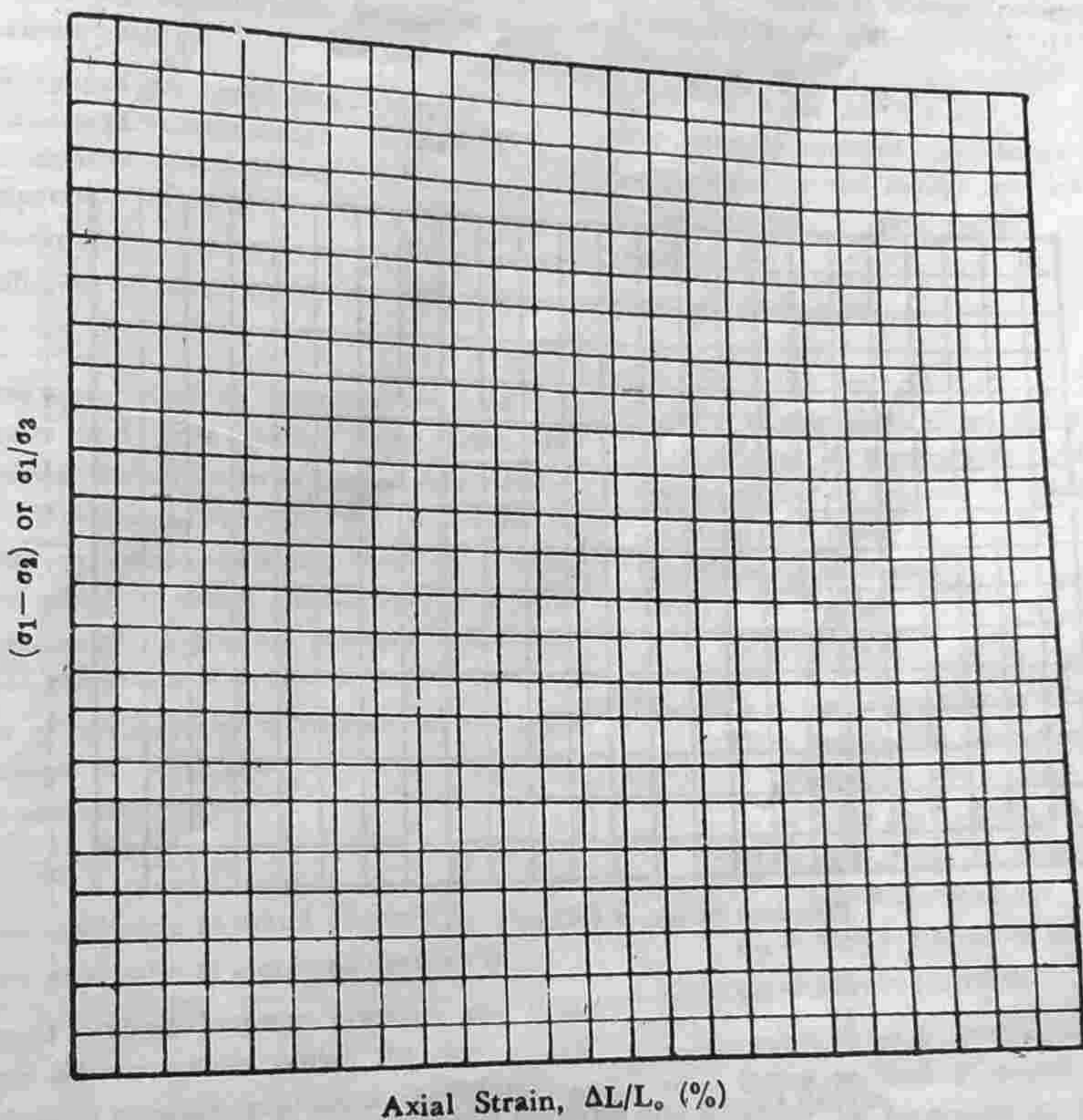
TRIAXIAL SHEAR TEST

OBSERVATIONS AND CALCULATIONS

Soil Sample No.

Recommended Graph Sheet 1

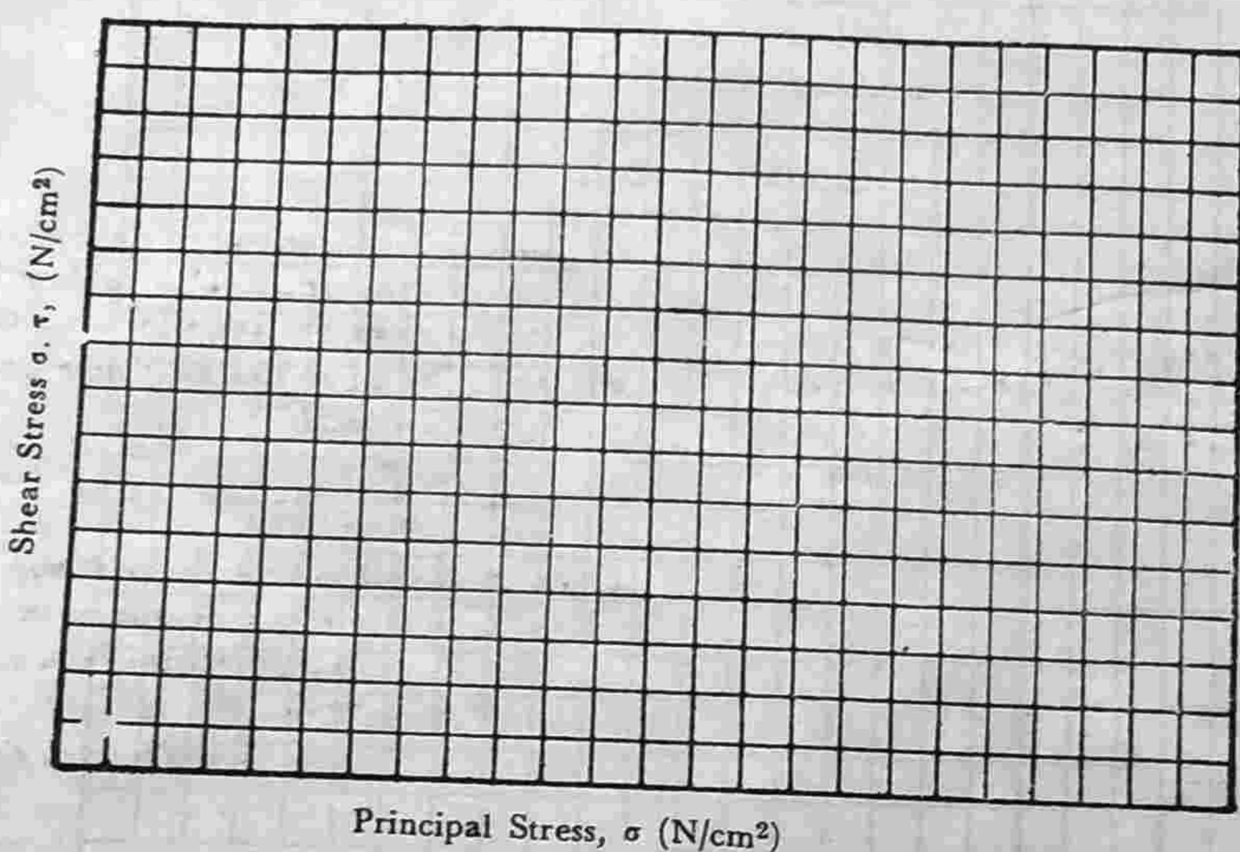
Date



Stress-Strain Curve

EXPERIMENT No. 12
TRIAXIAL SHEAR TEST
OBSERVATIONS AND CALCULATION

Soil Sample No. Recommended Graph Sheet 2 Date



Mohr's Circles and Strength Envelope

EXPERIMENT NO. 13

Consolidation Test

Object

To determine the consolidation properties of a given soil sample such as

(i) Coefficient of compressibility 'a$_v$'
(ii) Coefficient of volume chage 'm$_v$'
(iii) Coefficient of consolidation 'c$_v$'
(iv) Compression index 'C$_c$'
(v) Precompression pressure 'P$_o$'
(vi) Coefficient of permeability 'K'

Theory

If stresses are applied to saturated soil mass, the soil particles and pore water, being relatively incompressible, do not undergo appreciable volume changes. Volume change of the soil mass is mainly due to escape of water from the voids. The process which involves simultaneously a slow escape of water and a gradual pressure adjustment between the soil grains is termed as '*consolidation*'.

Coefficient of compressibility is defined as the ratio of the change in voids ratio to the corresponding change in pressure

$$a_v = \frac{e_1 - e}{p - p_1} \text{ or } \frac{-\Delta e}{\Delta p}$$

where e_1 = void ratio at initial pressure p_1

e = void ratio at increased pressure p

If a curve is plotted between pressure and void ratio, both on arithmetic scales, the slope of this curve at desired pressure represents the coefficient of compressibility.

In a soil mass, the change in volume per unit of initial volume due to a given unit increase in pressure is defined as *coefficient of volume change* m_v

$$m_v = \frac{-\Delta V}{V_1} \frac{1}{\Delta p}$$

Δv = change in volume

V_1 = initial volume

Δp = change in pressure (pressure increment)

In terms of voids ratio :

$$m_v = \frac{\Delta e}{1+e_1} \frac{1}{\Delta p} = \frac{a_v}{1+e_1}$$

For laterally confined soil, change in volume is proportional to the change in thickness ΔH and initial volume is proportional to the initial thickness H_1.

In terms of thickness :

$$m_v = \frac{\Delta H}{H} \frac{1}{\Delta p}$$

Coefficient of consolidation shows the combined effect of coefficient of permeability and coefficient of volume change on the rate of volume change of a soil mass. Its value can be determined by using the following equation :

$$C_v = \frac{T_v H^2}{t_{90} \text{ (or } t_{50})}$$

Where C_v = coefficient of consolidation

T_v = time factor, dimensionless

= 0.848 for 90% degree of consolidation

= 0.197 for 50% degree of consolidation

H = half of the thickness of the sample for two ways-drainage

t_{90} = time required for 90% consolidation

t_{50} = time required for 50% consolidation

The value of t_{90} is determined by square root of time fitting method proposed by Taylor, t_{50} is determined by logarithm of time fitting method suggested by Casagrande.

The term **compression index** C_c represents the slope of the liner portion of the pressure-voids ratio curve on a semi-log plot, it is expressed by the equation

$$C_c = \frac{e_1 - e}{\log_{10} p - \log_{10} p_1} = \frac{e_1 - e}{\log_{10} \Delta p}$$

$$= \frac{\Delta e}{\log_{10}\Delta p}$$

Precompression pressure is the greatest effective pressure to which the soil sample has been subjected to in-situ due to overburden. It is also called preconsolidation pressure It is detetermined by Qasagrande's emprical construction on the pressure-voids curve plotted on semi-log graph paper.

Coefficient of permeability is determined by the equation,

$$k = \frac{C_v \, a_v \, r_w}{(1 + e_1)} = C_v \, m_v \, r_w$$

Where k = coefficient of permeability

C_v = coefficient of consolidation

a_v = coefficient of compressibility

r_w = unit mass of the water

e_1 = initial voids ratio

Applications

The main aim of a consolidation test is to obtain soil data which are used in predicting the rate and amount of settlement of structure founded on clay primarily due to volume change of the clay. The following information can be obtained for foundations resting on clay :

(i) total settlement of foundation under any given load

(ii) time required for total settlement due to primary consolidation

(iii) settlement for any given time and load

(iv) time required for any percentage of total settlement or consolidation.

(v) pressure due to which soil already has been consolidated/compressed.

Apparatus

Special

1. Consolidometer
2. Loading device (jack or lever system)
3. Ring of non-corrosive material
4. Porous stones
5. Water reservoir

General

1. Soil trimming tools like fine wire saw, knife, spatula etc.
2. Balance (0.01 g sensitive)
3. Dial gauge (.01 mm accuracy)
4. Oven
5. Desiccator
6. Moisture content crucibles
7. Stop watch
8. Scale (0.5 mm least count)

Procedure

1. Clean the ring and weigh it empty
2. Measure the height and diameter of the consoildation ring
3. Insert the ring in the soil mass by pressing with hands and remove the material around the ring. The soil specimen so cut should project about one centimeter on either side of the ring.
4. Trim the specimen to flush it with the top and bottom of the ring.
5. Remove any soil sticking to the outside of the ring and weigh ring with the soil specimen.
6. Determine the moisture content of the extra soil removed from outside the ring.
7. Assemble the cosoildometer with the ring having the soil specimen and saturated porous stones at top and bottom of the specimen. Place filter paper between the soil specimen and the porous stones.
8. Mount the assembly on the loading frame and the dial gauge is set in position in such a way that the dial is at the beginning of its release run.
9. Connect the system to a reservoir with the level of water in the reservoir at about the same level as that of the specimen. Allow the water to flow into the sample, till it is saturated. During saturation, an initial setting pressure about of 0.50 N/cm^2[(a)] is applied to check the swelling.
10. After saturation, note initial reading of the dial gauge.
11. Apply the normal load to give the desired pressure intensity of 2.5 N/cm^2 on the soil specimen.
12. Note the dial gauge readings at elapsed times of 0, 0.25, 1.0, 2.25, 4, 9, 16, 25, 36, 49, 64, 81,

(a) For very soft soils a setting load of .25 N/cm^2 or less may be applied.

100, 169, 256, 361, 600, 1440 minutes from the instant of application of load. The dial gauge readings are taken until 90% consolidation is reached or for atleast 24 hours.

13. Increase the normal load to give the doubled pressure intensity of the previous pressure or 5.0 N/cm². Take the time and dial gauge readings as mentioned in step 12.

14. On successive days, apply the loads to give the pressures of 10, 20, 40 and 80 N/cm² or the desired pressure intensity(b).

15. After the last load is applied, decrease the load 1/4th the value of the last load i.e. 20 N/cm² and allow to stand for 24 hours.

16. Note the dial gauge reading after 24 hours.

17. Further reduce the load in steps of one-fourth the previous load and repeat the observations.

18. If data for repeated loading is required, the load intensity is increased and observations are repeated.

19. Finally reduced the load to the initial setting load, keep for 24 hours and the final dial gauge reading is recorded.

20. Dismantle the consolidation ring and weigh it after gently removing any surface water present.

21. Dry the specimen in the oven for 24 hours and weigh the dry soil specimen.

Precautions

1. The porous stones should be fully saturated by boiling in water for about 25 minutes.
2. The diameter of the top stone should be 0 2 to 0.5 mm less than the internal diameter of the ring.
3. Any voids in the soil sample caused due to removal of gravel etc. should be filled by loose soil, care should be taken not to effect the permeability of the specimen.
4. As far as possible there should be no change in water content, density and structure of the specimen during transportation and handling.
5. Load applied should be axial.
6. Throughout the test the container gutter should be kept filled with water.

Observations and Calculations

1. Use Table 1 for recording specimen dimensions weights and calculating the initial and final moisture contents, void ratios dry unit mass and degree of saturations.
2. Use Table 2 for recording the elapsed time and dial guage readings.
3. Use Table 3 for calculating void ratio coefficient of compressibility 'a_v' and coefficient of volume change 'm_v'.
4. Use simple graph papers for plotting compression on Y-axis and $\sqrt{t}$ on x-axis. Determine t_{90} for all pressures by square root of time fitting method.
5. Use semi-log graph paper for plotting compression on ordinary scale (Y-axis) and time on log scale (x-axis). Determine t_{50} by logarithm of time fitting method at all normal pressures.
6. Use Table 4 for calculating coefficient of consolidation 'C_v' and coefficient of permeability k.
7. Use simple graph paper for plotting pressure-void ratio curve.
8. Use semi-log graph paper for plotting void ratio on ordinary scale (Y-axis) and pressure intensity at log scale (x-axis). It gives e-log p curve.
9. Determine compression index 'C_c' by reading the slope of straight line portion of e-log p curve.
10. Determine preconsolidation pressure p_c on e-log p curve by simplified method.

Results

Average value of coefficient of compressibility.

a_v, (cm²/m) =

Average value of coefficient of consolidation,

c_v, (sq. cm/min) =

(b) Smaller increments may beapplied on very soft soil samples. Alternatively 5, 10, 25, 50, 100 and 200 percent of the maximum field intensity may be used.

Coefficient of permeability, k, (cm/min) =

Compression Index C_c =

Preconsolidation pressure p_c, (N/cm^2) =

e-p curve

e-log p curve

QUESTIONS

1. What do you understand by consolidation, compression and compaction ?
2. Define coefficient of compressibility and coefficient of volume change.
3. Define coefficient of consolidation. What is its significance ?
4. What are the factors affecting coefficient of consolidation ?
5. Define compression index. What are its applications ?
6. What are the methods of estimating the compression index ?
7. What do you understand by square root of time fitting method ? Who suggested it ?
8. What do you understand by logarithm of time fitting method ? Who gave it ?
9. What are Terzaghi's assumptions on consolidation theory ?
10. What do you understand by time factor ? Show the relationship between time factor and degree of consolidation.
11. What is the rate of consolidation ?
12. If a foundation is resting on clayey soil, how would you determine its total settlement and the corresponding time required ?
13. How do you estimate the settlement for a given period of time ?
14. What is preconsolidation pressure ? Why it is determined ?
15. What is approximate method of determination preconsolidation pressure ?
16. What is swelling index ? Can it be determined by consolidation test ?
17. Explain, under, normal and overconsolidated soils ? Which one is better for foundation ?
18. What are the factors affecting settlement of foundations resting on cohesive soils.
19. Distinguish between primary and secondary consolidation of soil.
20. How do a_v and m_v vary in a uniform soil with depth, increasingly or decreasingly ? Show your reasoning by calculations.
21. What is a 'virgin curve' ?
22. What is the effect of two-way drainage on time and magnitude of settlement ?

DISCUSSIONS

EXPERIMENT No. 13

OBSERVATIONS AND CALCULATIONS

TABLE 1

(For moisture content and preliminary computations)

Soil Sample No.

Date

(i) Diameter of the ring (cm) =

(ii) Area of the ring, A (cm^2) =

(iii) Height of the ring, H (cm) =

(iv) Volume of the ring, V (cm^3) =

(v) Specific gravity of solids, G_s =

		Beginning of test	End of test
(1) Mass of ring	(gm)		
(2) Mass of ring + sample	(gm)		
(3) Wet mass of sample, M	(gm)		
(4) Dry mass of sample, M_d	(gm)		
(5) Mass of water, M_w	(gm)		
(6) Moisture content, $w_w = \frac{M_w}{M_d} \times 100$	(%)		
(7) Dry unit mass, $r_d = M_d/V$	(gm/cc)		
(8) Wet unit mass, $rt = \frac{M}{V}$	(gm/cc)		
(9) Initial height of sample, H_1	(cm)		
(10) Total change in height, ΔH	(cm)		
(11) Final height of sample, $H_f = H_1 - \Delta H$	(cm)		
(12) Reduced height of solids, $H_s = M_s/G_s A \gamma_w$	(cm)		
(13) Void ratio, $e = \frac{H}{H_s} - 1$			
(14) Degree of saturation $S = \frac{w_w G_s}{e}$			

EXPERIMENT No. 13

OBSERVATIONS AND CALCULATIONS

TABLE 2

(For elapsed time, dial reading and compression)

Soil Sample No.

Date									
Time of starting									
Pressure intensity N/cm²		p1 =							
Elapse time (min.)	$\sqrt{t}$ (min.)	Dial gauge readings and compression							
		Reading	Comp. (mm)	Reading	Comp. (mm)	Reading	Comp. (mm)	Reading	Comp. (mm)
0	0								
0.25	0.5								
1.0	1.0								
2.25	1.5								
4.0	2.0								
9.0	3.0								
16.0	4 0								
25.3	5.0								
36.0	6.0								
49.0	7.0								
64.0	8.0								
81.0	9.0								
100.0	10.0								
189.0	13.0								
256.0	16.0								
361.0	19.0								
600.1	24.5								
1440.0	38.0								

If pressure are more, make addition tables. Readings of 1440 minutes time are called final dial gauge readings.

EXPERIMENT No. 13

OBSERVATIONS AND CALCULATIONS

TABLE 3

(for calculating e, a_v and m_v)

Soil Sample No. Date

Equivalent height of solids, $H_s = \frac{M_s}{G_s A \gamma_w} =$ (mm)

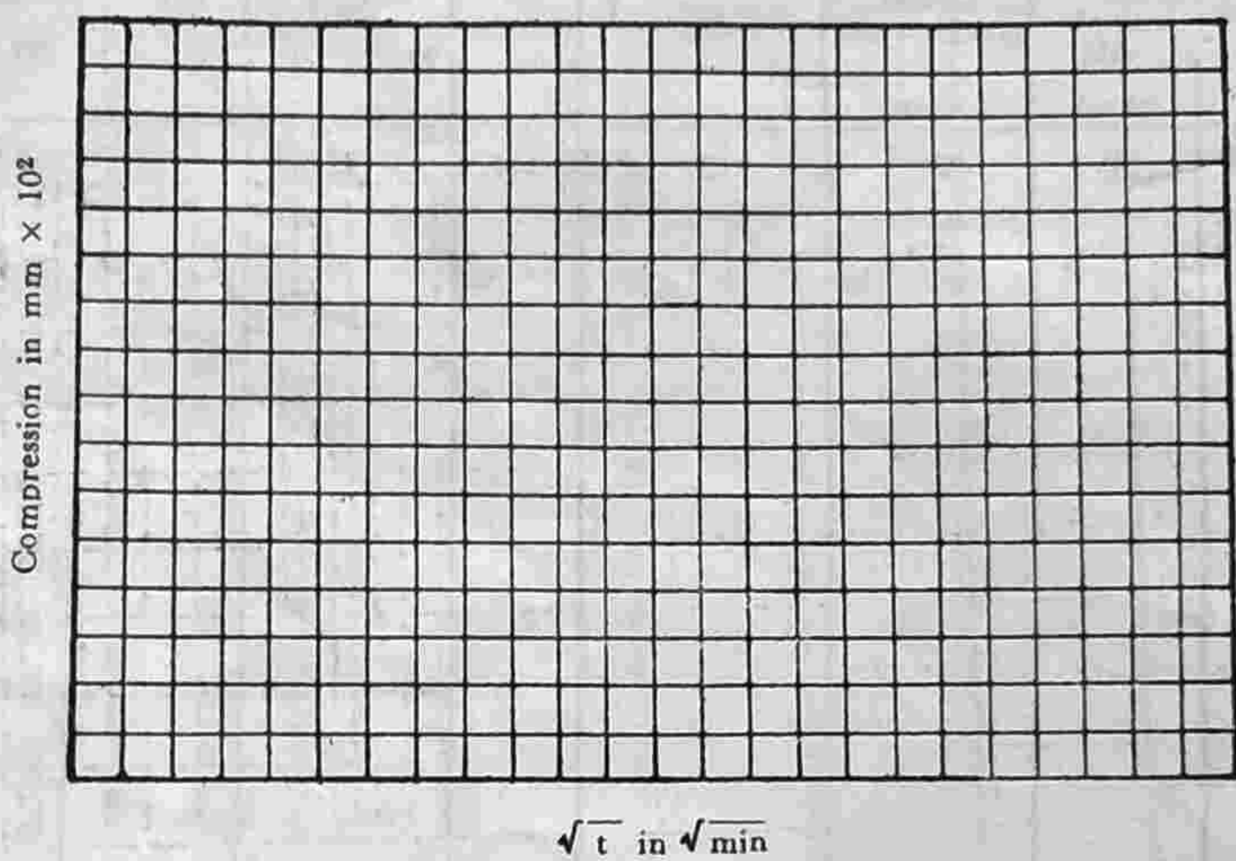
Initial height of the sample, $H_1 =$ (mm)

Applied pressure N/cm²	Final dial readings (mm)	Change in height of sample ΔH (mm)	Height of sample $H = H_1 - \Delta H$ (mm)	Void ratio $e = \frac{H}{H_s} - 1$	Δe	Coefficient of compressibility $a_v = -\frac{\Delta e}{\Delta p}$	$1 + e_1$	Coefficient of volume change $m_v = \frac{a_v}{1 + e_1}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
0								
2.5								
5.0								
10.0								
20.0								
40.0								
80.0								

EXPERIMENT No. 13
OBSERVATIONS AND CALCULATION

Soil Sample No. Recommended Graph Sheet 1 Date

Pressure intensity, p = (N/cm²)



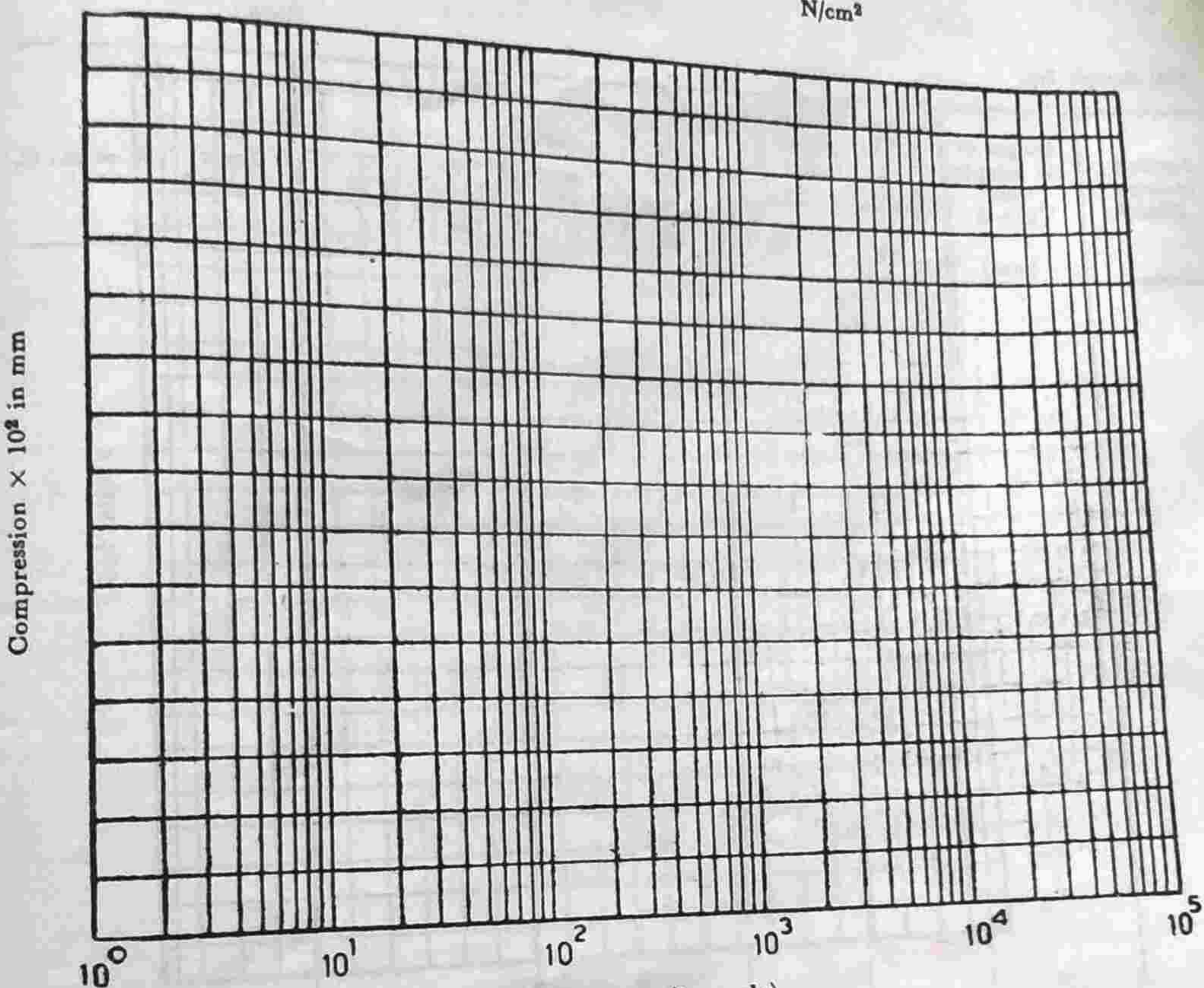
Determination of t_{90} by Square Root of Time Fitting Method

Use as many graph sheets as pressures

EXPERIMENT No. 13
OBSERVATIONS AND CALCULATIONS

Recommended Graph Sheet 2

Pressure intensity, p = N/cm²



Determination of t_{50} by Logarithm of Time Fitting Method

Use as many graph sheets as pressures.

EXPERIMENT No. 13

OBSERVATIONS AND CALCULATIONS

TABLE 4

(for determination of C_v and K)

Soil Sample No. Date :

Applied pressure N/cm^2	Height of soil sample from Table 3 (mm)	Fitting time (min)		C_v $cm^2/min.$		m_v from Table 3	$K = m_v C_v$
		t_{90}	t_{50}	$\frac{0.848}{t_{90}}\left(\frac{H}{2}\right)^2$	$\frac{0.197}{t_{50}}\left(\frac{H}{2}\right)^2$		

CONSOLIDATION TEST

EXPERIMENT No. 13

OBSERVATIONS AND CALCULATIONS

Soil Sample No.

Recommended Graph Sheet 3

Date

Void ratio, e

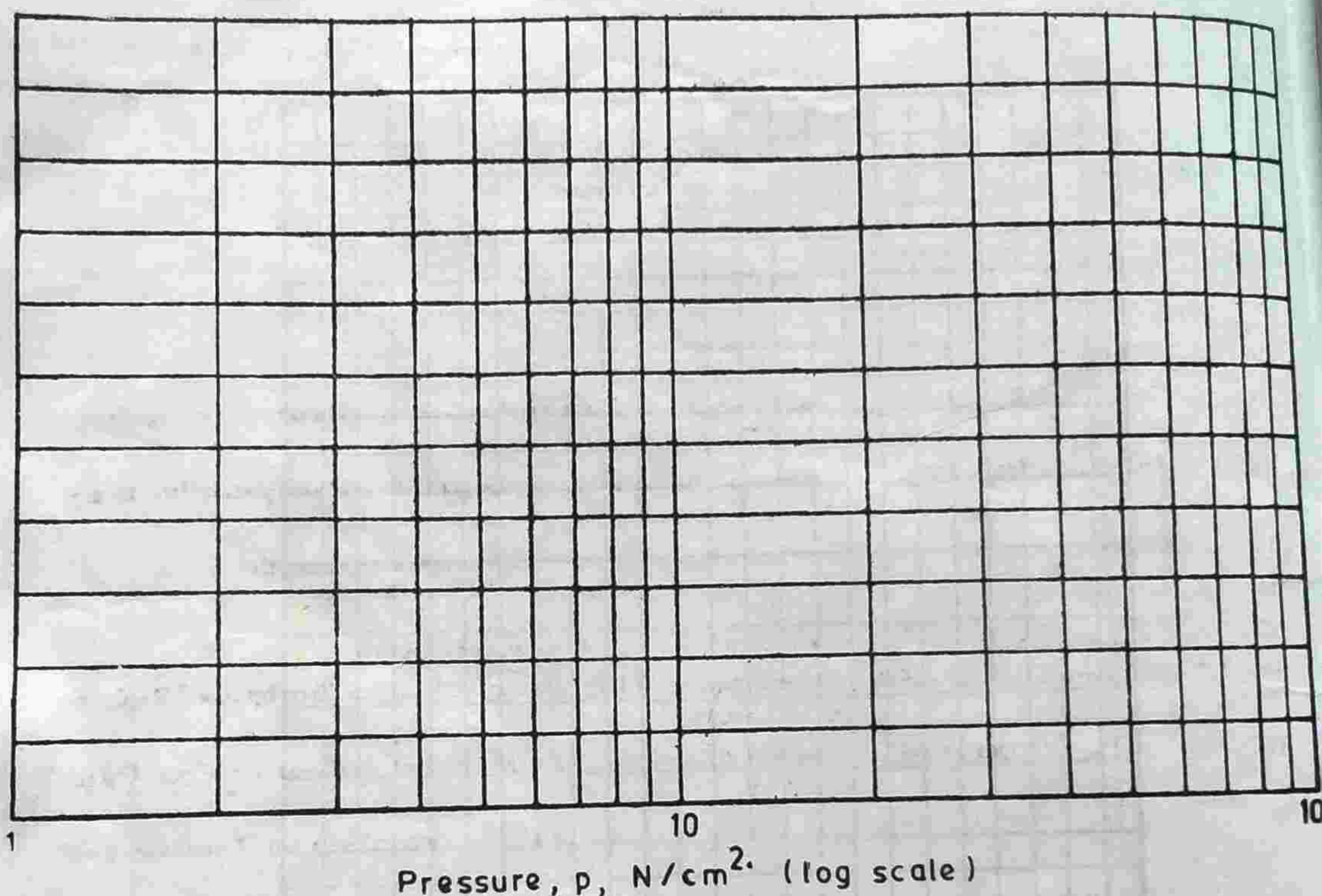
Pressure, N/cm²

Void Ratio - Pressure Relationship

EXPERIMENT No. 13

OBSERVATIONS AND CALCULATIONS

Soil Sample No. Recommended Graph Sheet 4 Date :



Appendix II

Specific Gravity of Water

Temp. °C	0	1	2	3	4	5	6	7	8	9
1	0.9999	0.9999	1.0000	1.0000	1.0000	1.0000	1.0000	0.9992	0.9999	0.9998
10	0.9997	0.9996	0.9995	0.9994	0.9991	0.9991	0.9900	0.9988	0.9986	0.9984
20	0.9982	0.9980	0.9978	0.9978	0.9973	0.9971	0.9968	0.9965	0.9963	0.9960
30	0.9957	0.9954	0.9951	0.9947	0.9944	0.9941	0.9937	0.9934	0.9930	0.9926
40	0.9922	0.9919	0.9915	0.9911	0.9907	0.9902	0.9898	0.9894	0.9890	0.9885
50	0.9881	0.9876	0.9872	0.9867	0.9862	0.9857	0.9852	0.9848	0.9842	0.9838
60	0.9832	0.9827	0.9822	0.9617	0.9811	0.9806	0.9800	0.9795	0.9789	0.9784
70	0.9778	0.9772	0.9767	0.9761	0.9755	0.9749	0.9743	0.9737	0.9731	0.9724
80	0.9718	0.9712	0.9706	0.9699	0.9693	0.9686	0.9680	0.9673	0.9667	0.9660
90	0.9653	0.9647	0.9640	0.9633	0.9626	0.9619	0.9612	0.9605	0.9598	0.9591

Appendix III

Viscosity of water

(Values given in millipoises)

Temp. °C	0	1	2	3	4	5	6	7	8	9
0	17.94	17.32	16.74	16.19	15.68	15.19	14.73	14.29	13.87	13.48
10	13.10	12.74	12.39	12.06	11.75	11.45	11.16	10.88	10.60	10.34
20	10.09	9.84	9.61	9.38	9.16	8.95	8.75	8.55	8.36	8.18
30	8.00	7.83	7.67	7.51	7.36	7.21	7.06	6.92	6.79	6.66
40	6.54	6.42	6.30	6.18	6.08	5.97	5.87	5.77	5.68	5.58
50	5.49	5.40	5.32	5.24	5.15	5.07	4.99	4.92	4.84	4.77
60	4.70	4.63	4.56	4.50	4.43	4.37	4.31	4.24	4.19	4.13
70	4.07	4.02	3.96	3.91	3.86	3.81	3.76	3.66	3.66	3.63
80	8.57	3.53	3.48	3.44	3.40	3.36	3.32	3.28	3.24	3.20
90	3.17	3.13	3.10	3.06	3.03	2.99	2.96	2.93	2.90	2.87
100	2.84	2.82	2.79	2.76	2.73	2.70	2.67	2.64	2.62	2.59

1 dyne sec/sq cm = 1 poise ; 1 gram sec/sq. cm = 980.7 poises

1 pound sec/sq. ft. = 478.69 poises ; 1 poises = 1000 millipoises

Appendix IV

Nomenclature

a	Cross-Sectional area of stand pipe
A	Cross-Sectional area of sample
A_c	Cotrected area at failure
A_e	Initial area
A^J	Cross-sectional area of jar
c	Cohesion
c′	Effective cohesion
c_u	Cohesion in undrained condition
C_c	Co-efficient of curvature
C_u	Co-efficient of uniformity
C_m	Correction due to meniscus
C_t	Correction due to temperature
C_d	Correction due to dispersing agent
CL	Clay of low compressibility
CI	Clay of medium compressibility
CH	Clay of high compressibility
d	Diameter
d_s	Average diameter of soil grains
D	Equivalent diameter of soil grains
D_{10}	Diameter of grains at 10% finer
D_{30}	Diameter of grains at 30% finer
D_{60}	Diameter of grains at 60% finer
e	Void ratio
F.I, I_F	Flow index
G_s	Specific gravity of soil grains/particles/solids
G	Gravel
GW	Well graded gravel
GP	Poorly graded gravel
GM	Silty gravel
GC	Clayey gravel
h	Distance or height
i	Hydraulic gradient
k	Co-efficient of permeability
L	Length of sample
L_o	Initial length of sample
L_s	Linear shrinkage
L.L, $\omega_{L.L.}$	Liquid limit
ML	Silt of low compressibility
MI	Silt of medium compressibility
MH	Silt of high compressibility
N	Number of blows
OL	Organic soil of low compressibility
OI	Organic soil of medium compressibility
OH	Organic soil of high compressibility
P.L, $\omega_{P.L.}$	Plastic limit
P.I., I_p	Plasticity index
P	Failure load
q	Discharge of water per unit time
q_u	Unconfined compressive strength
Q	Quantity of water/total discharge
r	Radius of sphere
R_h	Hydrometer reading
R_{c2}	Corrected hydrometer reading
S	Sand
Sd	Poorly graded sand
SW	Well graded sand
SM	Silty sand
SC	Clayey sand
S.L., $\omega_{S.L.}$	Shrinkage limit
SR	Shrinkage ratio
S	Degree of saturation
t	Time
T.I., I_T	Toughness index

u	Pore pressure
v	Velocity
V_H	Volume of hydrometer
V	Volume
VS	Volumetric shrinkage
w, w_w	Water content/moisture content
W	Weight/mass
W_w	Weight/mass of water
W_s, W_d	Weight/mass of solids/dry soil/grains
α	Failure angle
γ	Unit weight of soil/density of soil/weight per unit volume/mass density of soil
γ_s	Unit weight of sphere/mass density of sphere
γ_w	Unit weight of water/mass density of water
γ_b	Bulk density
γ_t	Unit weight of wet soil/mass density of wet soil
γ_d	Unit weight of dry soil/mass density of dry soil
γ_l	Unit weight of liquid/density of liquid
ξ	Strain
ΔL	Change in length
σ_1	Major principal stress
σ_3	Minor principal stress
σ_1, σ_{eff}	Effective normal stress
σ	Total normal stress
τ_f	Failure shear stress/shear resistance
ϕ	Angle of internal friction/shearing resistance
ϕ_1	Effective angle of shearing resistance
μ	Micron
η	Viscosity of liquid